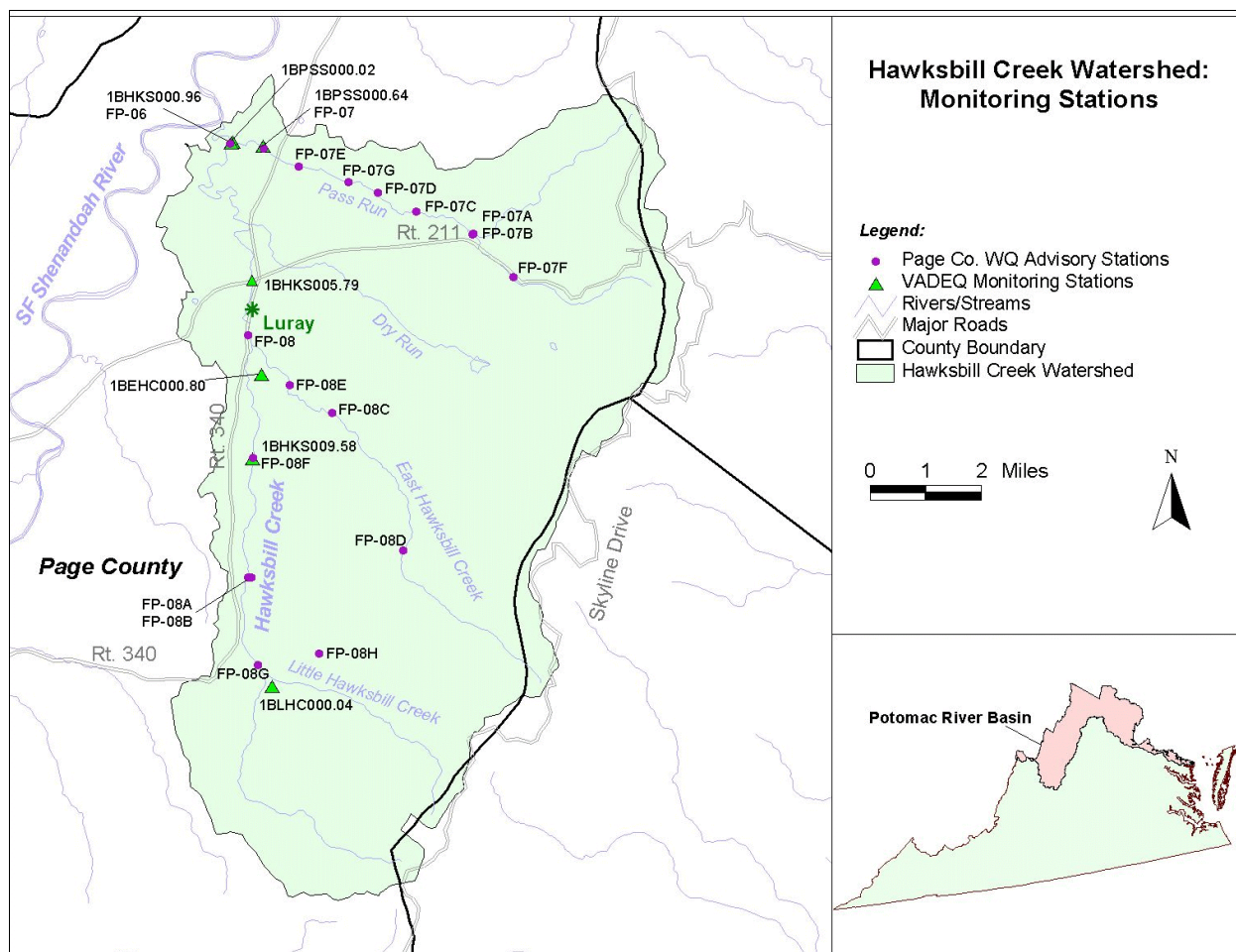


Total Maximum Daily Load (TMDL) Development for Hawksbill Creek

E. coli (Bacteria) Impairment



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Executive Summary

Impairment Listing

The Hawksbill Creek watershed (Virginia Waterbody Identification Code, VAV-B39R) is located in Page County in the Potomac River Basin (USGS Hydrologic Unit Code, 02070006) (Figure 1.1). Hawksbill Creek flows northward from its headwaters near Pine Grove, downstream through the Town of Luray to its confluence with the South Fork Shenandoah River. The Hawksbill Creek watershed is approximately 57,000 acres in size and land use is predominantly forest and agricultural.

Hawksbill Creek was listed as impaired on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report due to violations of the State's Water Quality Standards for fecal coliform bacteria. The Hawksbill Creek bacteria impaired segment is approximately 19.3 miles long and it begins at the headwaters and continues downstream to the confluence with the South Fork Shenandoah River.

Background

Elevated levels of fecal coliform bacteria and *E. coli* bacteria were recorded at several water quality monitoring stations on Hawksbill Creek. In order to improve water quality conditions that have resulted in bacteria impairments, a Total Maximum Daily Load (TMDL) was developed for the impaired stream, taking into account all sources of bacteria in the watershed, plus an implicit margin of safety (MOS). Upon implementation, the bacteria TMDL will ensure that water quality conditions relating to bacteria impairment will meet the recently adopted *E. coli* criteria in Virginia's Water Quality Standards (9 VAC 25-260-170).

Sources of Bacteria

Point and nonpoint sources of bacteria in the Hawksbill Creek watershed were considered in TMDL development. Agricultural runoff, wildlife, and past combined sewer overflows (CSOs) are listed as the possible sources of bacteria, according to the 2002 303(d) Fact Sheet for Hawksbill Creek. Nonpoint sources of bacteria include failing septic systems and straight pipes, livestock (including manure application loads), wildlife, and domestic pets. Point sources, such as municipal sewage treatment plants, can contribute bacteria loads to surface waters through effluent discharges. There are currently three point source permits in the Hawksbill Creek watershed that discharge bacteria.

Table 1. VPDES point sources and existing loads

Permit No.	Facility	Flow (MGD)	Permit Limit (E. coli cfu/100ml)	Existing Annual Load (E. coli cfu/yr)
VA0024406	Big Meadows STP	0.13	126	2.26E+11
VA0024422	Skyland Developed Area	0.07	126	1.22E+11
VA0062642	Luray STP	1.60	126	2.79E+12
Total	All Permits	1.80		3.13E+12

Modeling

An *E. coli* TMDL was developed using the Loading Simulation Program C++ (LSPC) model. LSPC is a watershed modeling system that includes streamlined Hydrologic Simulation Program Fortran (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land as well as a simplified stream transport model.

Weather conditions are the driving force for watershed hydrology processes. For the Hawksbill Creek watershed simulation model, the required parameters included hourly precipitation and hourly potential evapotranspiration. The Luray 5 E (445096) daily weather station is located in the Hawksbill Creek watershed. Weather data collected at this station were used to setup the LSPC model. Available daily precipitation data were disaggregated to hourly measurements based on the hourly distribution of nearby weather stations.

The selection of a representative modeling period is typically based on the availability of streamflow, weather, and water quality data for the modeled watershed. There is not a USGS streamflow gage located in the Hawksbill Creek watershed; therefore, the nearby Smith Creek watershed (Shenandoah and Rockingham Counties) was used as a reference watershed. Hourly streamflow data from the Smith Creek USGS gage (01632900) were used to calibrate hydrology. Representative flow data were available from 1980 through 2002. Two time periods were selected for hydrology calibration: 1990 through 1991 and 1996 through 1997. The land use coverage used in the model was developed during the mid 1990s; therefore, the selected calibration periods were consistent with this key model input. The model was then validated for long-term and seasonal representation of hydrologic trends using the current 13-year period (1990-2002). The calibration and validation periods covered a range of hydrologic conditions, including low and high flow conditions, as well as seasonal variation. The calibrated LSPC model adequately simulated the hydrology of the impaired watershed.

Hydrology parameters for the Hawksbill Creek watershed were based on the final parameters used in the Smith Creek reference watershed calibrated model. These parameters were used to establish the flow response and water balance in the Hawksbill Creek watershed, which has very similar geologic, soils, landuse, topography, and other key watershed attributes. Water quality calibration

was based on comparing the fecal coliform bacteria data collected on Hawksbill Creek to the simulated concentrations.

Existing Conditions

The LSPC model was run for the representative hydrologic period January 1, 1990 through December 31, 2002. The modeling run represents the existing *E. coli* concentrations and loadings at the watershed outlet, using the DEQ fecal coliform bacteria/*E. coli* translator. These data were compared to the 126 cfu/100mL geometric mean and 235 cfu/100mL instantaneous (single sample) water quality standards for *E. coli* to assess the magnitude of in-stream concentrations. Existing *E. coli* loadings by source category for Hawksbill Creek are presented in Section 5. These values represent the contribution of bacteria from all sources in the watershed.

Margin of Safety

While developing allocation scenarios for the Hawksbill Creek bacteria TMDL, an implicit margin of safety (MOS) was used. Conservative assumptions, the use of a detailed watershed model (LSPC), and other considerations were used in developing bacteria TMDLs, such that an explicit MOS was not necessary.

Allocation Scenarios

Load or wasteload allocations were assigned to each source category in the watershed. Various allocation scenarios were examined for reducing *E. coli* loads to levels that would result in the attainment of water quality standards (Table 2). Scenario 8 presents the source reductions required to achieve the *E. Coli* instantaneous and calendar month geometric mean criteria. Scenario 5 presents the reductions required to meet the Stage 1 implementation goal of <10% violation of the instantaneous criteria. Reductions in load contributions from in-stream sources had the greatest impact on *E. coli* concentrations. Significant reductions from land-based loadings were also required to meet the geometric mean standard.

Table 2. TMDL allocation scenarios and percent violations

Scenario Number	Direct (Instream) Sources			Indirect (NPS) Sources				Percent Violations	
	Straight Pipes	Livestock	Wildlife	Cropland	Pasture	Built up	Forest	Inst. Exceeds 235 cfu/100ml	Geom. Exceeds 126 cfu/100ml
1	0	0	0	0	0	0	0	27%	59%
2	100	25	0	25	25	50	0	19%	33%
3	100	50	0	40	40	50	0	14%	15%
4	100	75	0	50	50	75	0	11%	7%
5	100	80	0	60	60	80	0	10%	3%
6	100	80	0	75	75	80	0	8%	1%
7	100	95	0	90	90	95	0	2%	0%
8	100	97	0	97	97	97	0	0%	0%

The TMDL consists of a point source wasteload allocation (WLA), a nonpoint source load allocation (LA), and an implicit margin of safety (MOS).

The WLA portion of this equation is the total loading assigned to point sources. The LA portion represents the loading assigned to nonpoint sources. The MOS is the portion of loading reserved to account for any uncertainty in the data and the computational methodology used for the analysis. TMDL allocations for Hawksbill Creek (under Scenario 8) are presented in Tables 3 through 5.

Table 3. Existing and allocation loads for LAs under allocation scenario 8

Sources		Total Annual Loading for Existing Conditions (cfu/yr)	Total Annual Loading for Allocation Conditions (cfu/yr)	Percent Reduction
Direct	Straight Pipes	<1.00E+4	<1.00E+4	100%
	Livestock	2.28E+13	6.85E+11	97%
	Wildlife	6.76E+12	6.76E+12	0%
Indirect	Cropland*	4.13E+13	1.24E+12	97%
	Pasture**	9.32E+13	2.80E+12	97%
	Built up***	9.32E+13	2.80E+12	97%
	Forest****	1.26E+12	1.26E+12	0%
Total		2.59E+14	1.55E+13	94%

* Includes Stipmining and Barren

** Includes Hayland

*** Includes Non MS4 Urban Pervious and Urban Impervious

**** Includes Wetland

Table 4. Existing and allocation loads for WLAs under allocation scenario 8

Sources	Total Annual Loading for Existing Conditions (cfu/yr)	Total Annual Loading for Allocation Conditions (cfu/yr)	Percent Reduction
Permits*	3.13E+12	3.13E+12	0%

* Total for all permits

Table 5. *E. coli* TMDL for Hawksbill Creek

WLA	LA	MOS	TMDL
3.13E+12	1.55E+13	Implicit	1.87E+13

SECTION 1

INTRODUCTION

1.1 Background

1.1.1 TMDL Definition and Regulatory Information

Section 303(d) of the Clean Water Act and EPA's Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are exceeding water quality standards. TMDLs represent the total pollutant loading that a waterbody can receive without violating water quality standards. The TMDL process establishes the allowable loadings of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. By following the TMDL process, states can establish water quality based controls to reduce pollution from both point and nonpoint sources to restore and maintain the quality of their water resources (USEPA 1991).

1.1.2 Impairment Listing

Hawksbill Creek was listed as impaired on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report due to violations of the State's Water Quality Standards for fecal coliform bacteria. The stream was initially listed as impaired in 1996. The Hawksbill Creek bacteria impaired segment is approximately 19.3 miles long and it begins at the headwaters and continues downstream to the confluence with the South Fork Shenandoah River.

1.1.3 Watershed Location

The Hawksbill Creek watershed is located in Page County in the Potomac River Basin (USGS Hydrologic Unit Code, 02070006) (Figure 1.1). Hawksbill Creek flows northward from its headwaters near Pine Grove, downstream through the Town of Luray to its confluence with the South Fork Shenandoah River. The waterbody identification code (WBID, Virginia Hydrologic Unit) is VAV-B39R.

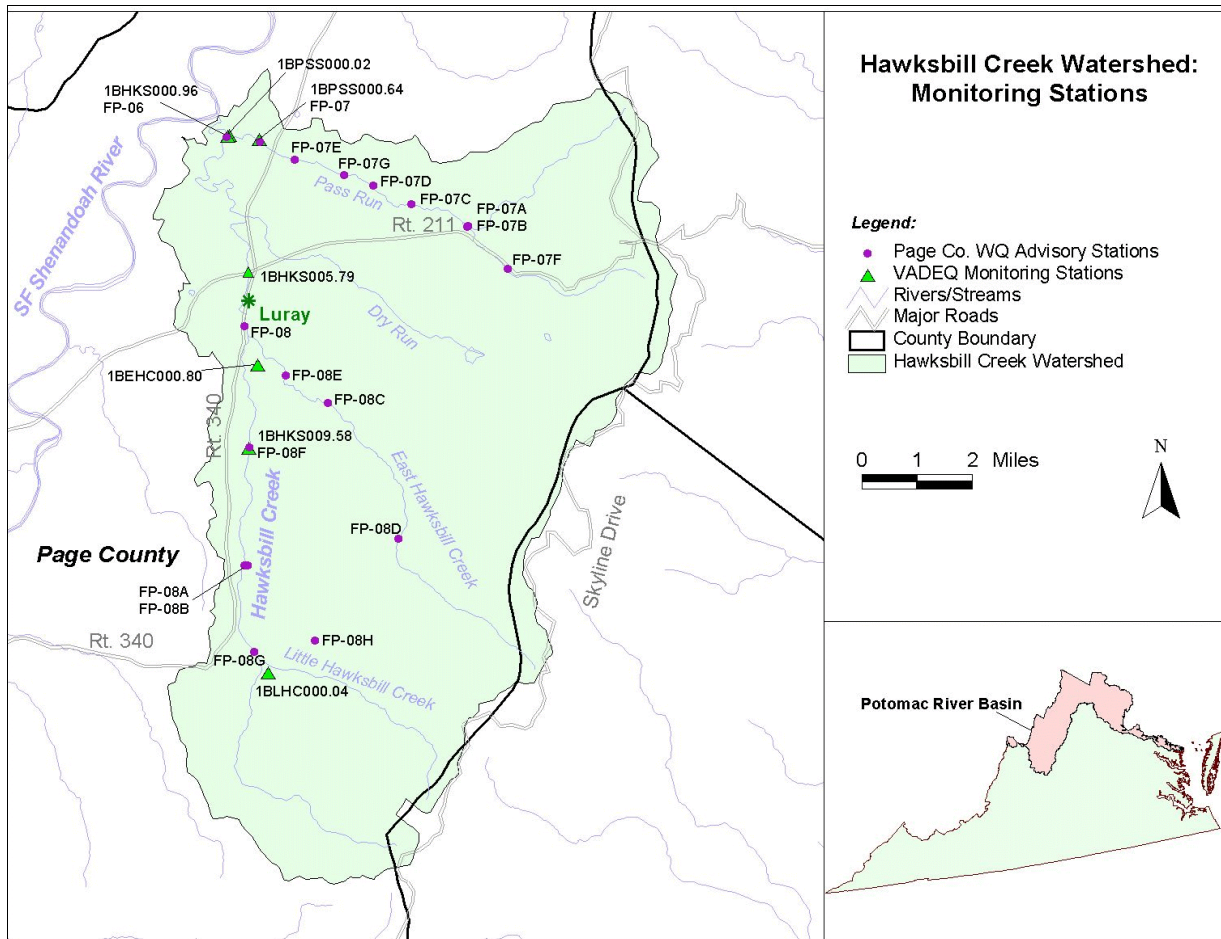


Figure 1.1 Location of the Hawksbill Creek watershed

1.2 Designated Uses and Applicable Water Quality Standards

According to Virginia's Water Quality Standards (9 VAC 25-260-5), the term "Water quality standards" means provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law (§ 62.1-44.2 et seq. of the Code of Virginia) and the federal Clean Water Act (33 USC § 1251 et seq.).

1.2.1 Designation of Uses (9 VAC 25-260-10)

A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.

Hawksbill Creek does not support the recreation (swimming) designated use due to violations of the Bacteria Criteria.

1.2.2 Water Quality Standards

Bacteria (9 VAC 25-260-170)

Hawksbill Creek was listed as impaired for non-compliance with the following fecal coliform bacteria criteria:

- A. *General Requirements: In all surface waters, except shellfish waters and certain waters addressed in subsection B of this section, the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 ml at any time.*

Virginia's Water Quality Standards were amended to include new criteria for fecal coliform bacteria, *E. coli*, and *enterococci*. Standards were adopted for *E. coli* and *enterococci* because of the higher correlation between *E. coli* and *enterococci* concentrations and gastrointestinal illness. These new criteria became effective on January 15, 2003. Fecal coliform bacteria and *E. coli* criteria apply to Hawksbill Creek, which is a freshwater stream. Bacteria concentrations are expressed as the number of colony forming units per 100ml of water (cfu/100ml):

- A. *In surface waters, except shellfish waters and certain waters identified in subsection B of this section, the following criteria shall apply to protect primary contact recreational uses:*
 - 1. *Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 ml of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.*
 - 2. *E. coli and enterococci bacteria per 100 ml of water shall not exceed the following:*

	Geometric Mean ¹	Single Sample Maximum ²
<i>Freshwater³</i>		
<i>E. coli</i>	126	235
<i>Saltwater and Transition Zone³</i>		
<i>enterococci</i>	35	104

¹ For two or more samples taken during any calendar month.

² No single sample maximum for enterococci and *E. coli* shall exceed a 75% upper one-sided confidence limit based on a site-specific log standard deviation. If site data are insufficient to establish a site-specific log standard deviation, then 0.4 shall be used as the log standard deviation in freshwater and 0.7 shall be as the log standard deviation in saltwater and transition zone. Values shown are based on a log standard deviation of 0.4 in freshwater and 0.7 in saltwater.

³ See 9 VAC 25-260-140 C for freshwater and transition zone delineation.

1.3 Water Quality Assessment and TMDL Endpoint Selection

Hawksbill Creek was listed as impaired for fecal coliform bacteria on Virginia's 303(d) list based on monitoring conducted by VADEQ. Elevated levels of fecal coliform bacteria were recorded at water quality monitoring stations on Hawksbill Creek. VADEQ began monitoring for *E. coli* in 2000 in anticipation of the change in indicator species. Elevated levels of *E. coli* have also been recorded on Hawksbill Creek. As a result, Hawksbill Creek does not currently support the Recreation (swimming) designated use.

TMDL development requires the identification of a numeric endpoint that will allow for the attainment of designated uses and water quality criteria. The new fecal coliform bacteria criteria specified in 9 VAC 25-260-170 shall not apply after a minimum of 12 samples for *E. coli* have been collected or after June 30, 2008, whichever comes first. As a result, the applicable TMDL endpoint is compliance with the recently adopted *E. coli* criteria. Virginia's Water Quality Standards specify a maximum *E. coli* bacteria concentration of 235 cfu/100ml, at any time, and a geometric mean criteria of 126 cfu/100 ml for two or more samples over the calendar month period (9 VAC 25-260-170).

SECTION 2

WATERSHED CHARACTERIZATION AND MONITORING SUMMARY

2.1 Watershed Characterization

2.1.1 General Information

The Hawksbill Creek watershed (Virginia Waterbody Identification Code, VAV-B39R) is located in the Potomac River Basin in Page County, Virginia (USGS Hydrologic Unit Code, 02070005) (Figure 1.1). The Hawksbill Creek watershed is approximately 57,000 acres in size and land use is predominantly forest and agricultural.

2.1.2 Geology

The Hawksbill Creek watershed is located in the Shenandoah Valley of Virginia, which is part of the Valley and Ridge physiographic province. The Valley and Ridge physiographic province is a belt of folded and faulted clastic and carbonate sedimentary rocks situated west of the Blue Ridge crystalline rocks and east of the Appalachian Plateaus. The Shenandoah Valley makes up part of the Great Valley subprovince, which extends from New York southwest to Alabama. This area is characterized by broad valleys with low to moderate slopes underlain by carbonate rocks. Limestone and dolomite (which are carbonate rocks) occur beneath the surface forming the most productive aquifers in Virginia's consolidated rock formations. The gently rolling lowland of the valley floor lies at an elevation of approximately 1000 feet above sea level. Sinkholes, caves, and caverns are common in the valley due to its karst geology.

2.1.3 Soils

Soils data were obtained from the State Soil Geographic (STATSGO) database which includes general soils data and map unit delineations for the United States. GIS coverages provide accurate locations for the soil map units (MUIDs) at a scale of 1:250,000 (Figure 2.1) (NRCS 1994). A map unit is composed of several soil series having similar properties. The following soil series descriptions are based on NRCS Official Soil Descriptions (1998-2002).

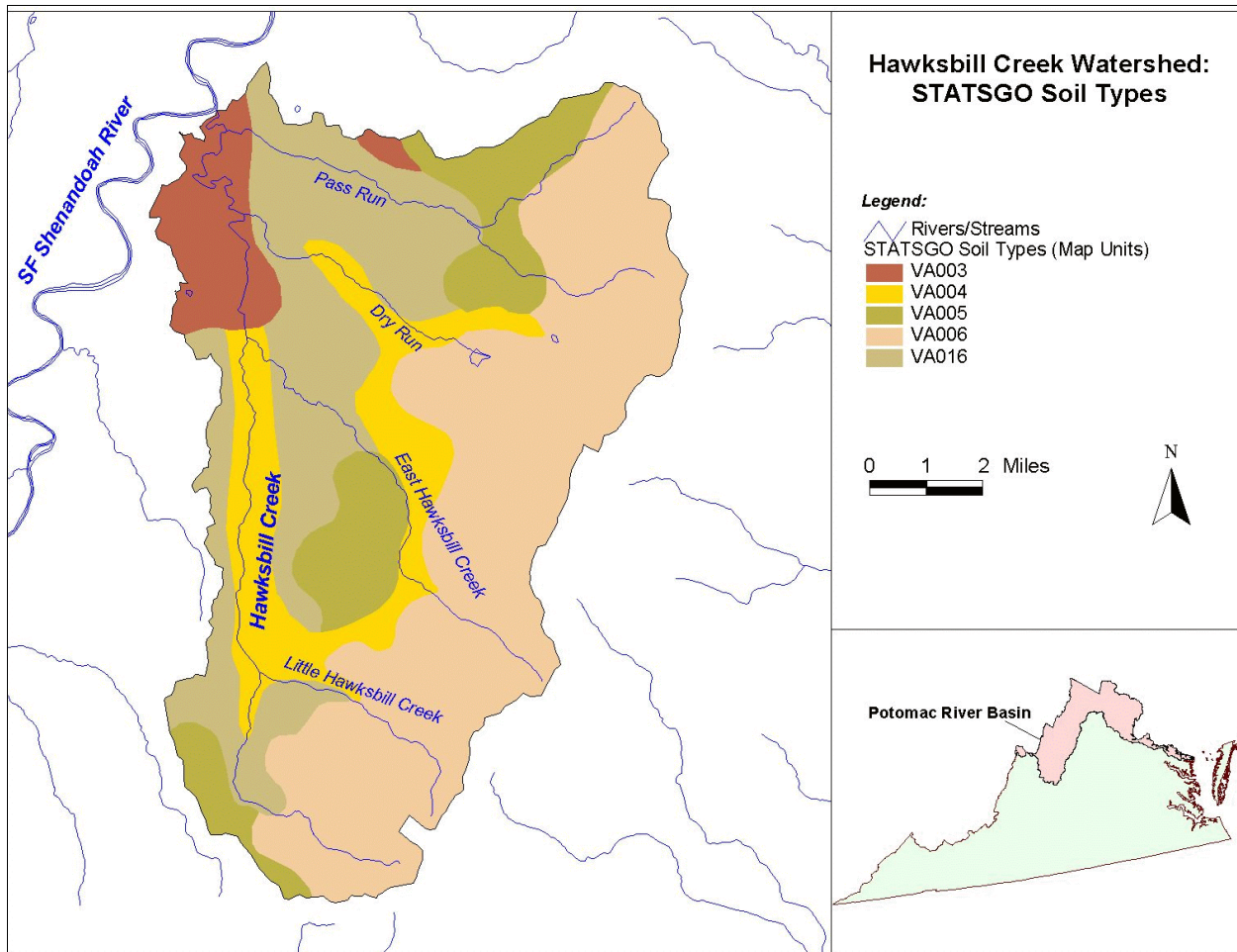


Figure 2.1 STATSGO soil types in the Hawksbill Creek watershed

STATSGO Soil Type VA003 is composed of the Frederick and Carbo series. The Frederick series accounts for most of the map unit. This series consists of very deep, well drained soils formed in residuum derived mainly from dolomitic limestone with interbeds of sandstone, siltstone, and shale. These soils are on nearly level to very steep uplands and slopes range from 0 to 66 percent. Permeability is moderate.

STATSGO Soil Type VA004 is composed of the Moomaw, Jefferson, and Alonzville series. The Moomaw series accounts for most of the map unit and consists of very deep, moderately well drained, slowly or moderately slowly permeable soils on stream terraces. These soils have a fragipan. These soils are formed in alluvium derived from acid sandstone, quartzites, and shales. Slopes range from 0 to 30 percent.

STATSGO Soil Type VA005 is composed of the Wallen and Dekalb. The Wallen series is the dominant soil type in the map unit. This soil series consists of moderately deep, somewhat

excessively drained soils that formed in residuum or colluvium and residuum weathered from fine-grained sandstone, siltstone, and shale. These soils are found on mountaintops and on mountain sides that are dominantly south and west facing. Slopes range from 2 to 85 percent.

STATSGO Soil Type VA006 is composed primarily of the Catocin and Myersville series. The Catocin series is the dominant soil type in the map unit. This series consists of moderately deep, well drained soils with moderately rapid permeability that formed in material weathered primarily from greenstone. These soils are found on nearly level to very steep ridges and side slopes. Slopes range from 0 to 80 percent.

STATSGO Soil Type VA016 is composed primarily of the Shottower, Laidig, and Weikert series. The Shottower series is the dominant soil series in the map unit. This series consists of very deep, well drained, moderately permeable soils on high stream terraces. These soils formed in old alluvium derived from sandstone, quartzite, limestone, shale, and siltstone. Slopes range from 2 to 30 percent.

2.1.4 Climate

The area's climate is typical of other regions in the Shenandoah Valley. Weather data for the Hawksbill Creek watershed can be characterized using the Luray 5 E meteorological station (NCDC), which is located within the watershed (period of record: 1948-2003). The growing season lasts from May 5 through October 10 in a typical year (SERCC 2003). Average annual precipitation is 39.80 inches with September having the highest average precipitation (4.05 inches). Average annual snowfall is 24.06 inches, most of which occurs in January and February. The average annual maximum and minimum daily temperature is 66.6°F and 40.4°F, respectively. The highest monthly temperatures are recorded in July (86.8°F - avg. maximum) and the lowest temperatures are recorded in January (20.8°F - avg. minimum).

2.1.5 Land Use

General land use/land cover data for the Hawksbill Creek watershed were extracted from the Multi-Resolution Land Characterization (MRLC) database for the state of Virginia (USEPA 1992) and is shown in Figure 2.1. This database was derived from satellite imagery taken during the early 1990s and is the most current detailed land use data available. Tetra Tech and VADEQ personnel performed ground-truthing during the course of the study in order to verify that the watershed land use coverage is accurate. A few minor discrepancies were noted and these adjustments were accounted for in the data. Land uses in the Hawksbill Creek watershed include various urban, agricultural, and forest categories (Table 2.1 and Figure 2.2). Approximately 60% of the watershed is forested, while approximately 35% of the watershed is used for agricultural purposes. Residential and commercial development account for approximately 5% of the watershed.

Table 2.1 MRLC land uses in the Hawksbill Creek watershed

MRLC Land Use	Acres	Percent	Consolidated Land Use	Acres	Percent
Deciduous Forest	23,457	41.19%	Forest	35,065	61.57%
Evergreen Forest	2,317	4.07%			
Mixed Forest	9,217	16.18%			
Emergent Wetlands	64	0.11%			
Woody Wetlands	10	0.02%			
Open Water	132	0.23%	Water	132	0.23%
Pasture/Hay	17,374	30.51%	Pasture/Hay	17,374	30.51%
Row Crops	1,675	2.94%	Row Crops	1,675	2.94%
Transitional	64	0.11%	Transitional	64	0.11%
Low Intensity Residential	2,502	4.39%	Urban	2,641	4.64%
High Intensity Residential	42	0.07%			
Commercial/Industrial/Transportation	97	0.17%			
Total	56,950	100.00%		56,950	100.00%

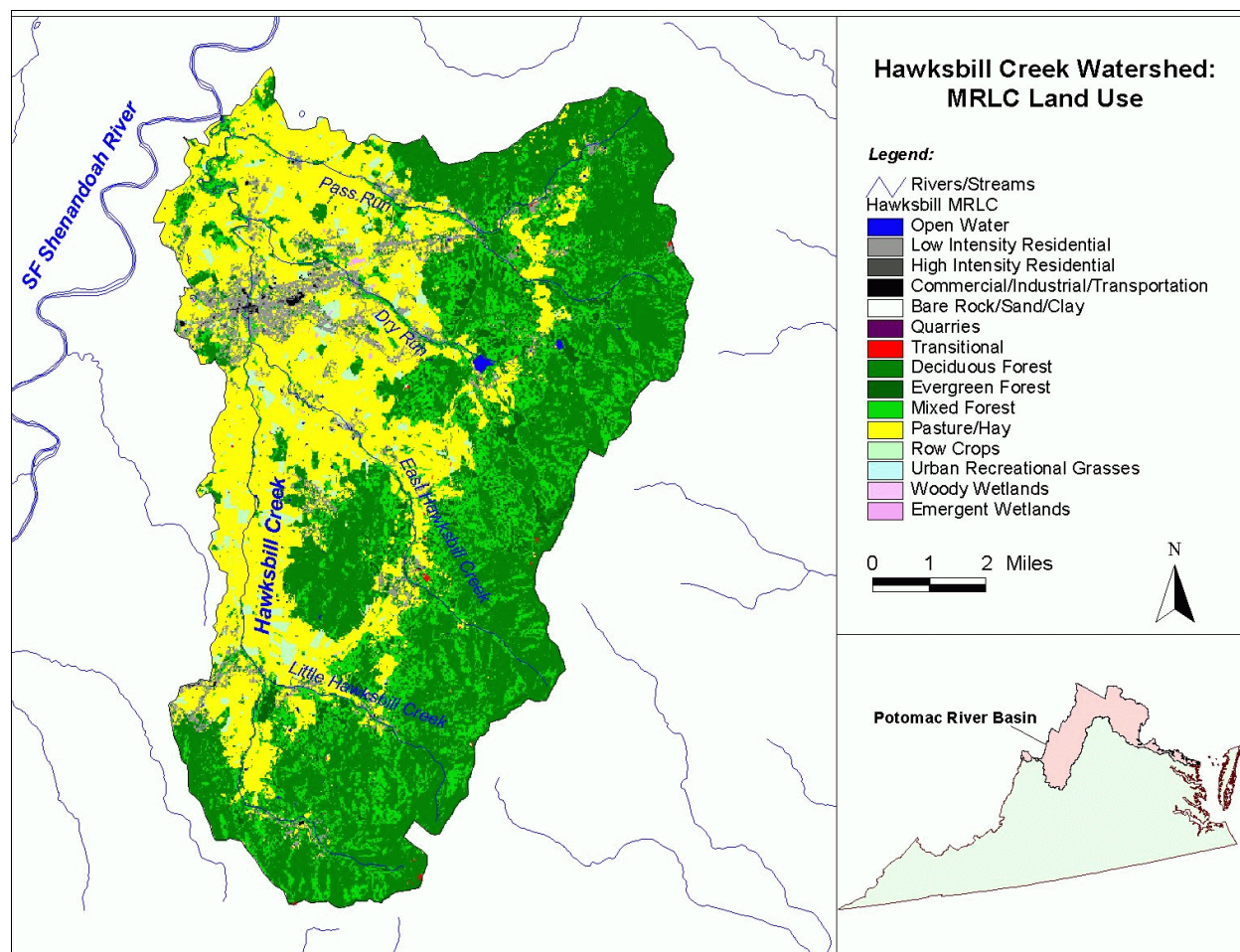


Figure 2.2 MRLC land uses in the Hawksbill Creek watershed

2.2 Stream Characterization

Hawksbill Creek flows north from its headwaters to its confluence with the South Fork Shenandoah River. Hawksbill Creek flows predominantly thorough pasture/hay and forest lands, but passes through a few urban areas including the Town of Luray downstream. Streams in the lower portion of the watershed flow through large expanses of pasture land and are utilized for livestock watering in some areas and other agricultural production activities. Hawksbill Creek passes through the Town of Luray a few miles upstream of its confluence with the South Fork Shenandoah. Major tributaries to Hawksbill Creek include Pass Run, Dry Run, East Hawksbill Creek, Little Hawksbill Creek, and Chubb Run.

2.3 Water Quality and Monitoring Summary

2.3.1 Monitoring Stations

There are 10 current and historical DEQ water quality monitoring stations located in the Hawksbill Creek watershed. Data from these monitoring stations were used to assess Hawksbill Creek as impaired. Additionally, the Page County Water Quality Advisory Committee conducted water quality monitoring at 18 stations in the Hawksbill Creek watershed. DEQ and Page County Water Quality Advisory Committee monitoring stations located in the Hawksbill Creek watershed are presented in Table 2.2 and shown in Figure 2.3.

Table 2.2 Monitoring stations in the Hawksbill Creek watershed

Station	Organization	Station Type	Location	Data Period
1BHKS000.96	VADEQ	WQ	Lower Hawksbill at Rt. 648 bridge	1968-2003
1BHKS005.79	VADEQ	WQ	Rt. 211 bridge	1999-2003
1BHKS005.85	VADEQ	WQ	Luray STP	1972-1974
1BHKS006.04	VADEQ	WQ	Immediately below Luray STP	1972-1979
1BHKS006.23	VADEQ	WQ	Rt. 675 bridge in Luray	1968-1979
1BHKS009.58	VADEQ	WQ	Upper Hawksbill at Rt. 640 bridge	1991-2003
1BPSS000.02	VADEQ	WQ	Pass Run at mouth	2002-2003
1BPSS000.64	VADEQ	WQ	Pass Run at Rt. 658 bridge	1994-2003
1BEHC000.80	VADEQ	WQ	East Hawksbill at Luray Recreational Park off 6th Street	2002-2003
1BLHC000.04	VADEQ	WQ	Little Hawksbill at Rt. 626 bridge	2002-2003
FP-06	Page County WQ Advisory Committee	WQ	Lower Hawksbill Creek	1998-2001
FP-07	Page County WQ Advisory Committee	WQ	Pass Run downstream	1998-2001
FP-07A	Page County WQ Advisory Committee	WQ	Pass Run at Rocky Branch	1999-2001
FP-07B	Page County WQ Advisory Committee	WQ	Pass Run at Jewell Hollow	1999-2001
FP-07C	Page County WQ Advisory Committee	WQ	Pass Run at Kimball Rd. bridge	1999-2000
FP-07D	Page County WQ Advisory Committee	WQ	Pass Run at Lyn-Mar Rd.	1999-2001
FP-07E	Page County WQ Advisory Committee	WQ	Pass Run at Bold Spring	2000-2001
FP-07F	Page County WQ Advisory Committee	WQ	Pass Run at Park HQ/US 211	1999-2001
FP-07G	Page County WQ Advisory Committee	WQ	Pass Run at Whispering Hill Rd.	2000
FP-08	Page County WQ Advisory Committee	WQ	Hawksbill Creek at Linden Street	1998-2001
FP-08A	Page County WQ Advisory Committee	WQ	Hawksbill Creek at Rt. 631	1999-2001
FP-08B	Page County WQ Advisory Committee	WQ	Chubb Run at Rt. 611	1999-2001
FP-08C	Page County WQ Advisory Committee	WQ	East Hawksbill at East Branch Rd.	1999-2001
FP-08D	Page County WQ Advisory Committee	WQ	East Hawksbill at Cross Mountain Rd.	1999-2000
FP-08E	Page County WQ Advisory Committee	WQ	East Hawksbill at Stonyman Rd.	2000-2001
FP-08F	Page County WQ Advisory Committee	WQ	Hawksbill Creek at Redman Store Rd. (Rt. 629)	2000-2001
FP-08G	Page County WQ Advisory Committee	WQ	Hawksbill Creek at Marksville bridge	2000-2001
FP-08H	Page County WQ Advisory Committee	WQ	Chubb Run at Ida Rd. (Rt. 689)	2000

2.3.2 Fecal Coliform Bacteria and *E. coli* Data

Data collected by VADEQ from 1991 to present were compared to the new instantaneous and geometric mean criteria for fecal coliform bacteria and *E. coli*. Bacteria Source Tracking (BST) data were also collected by VADEQ at station 1BHKS000.96 from 9/9/02 through 8/11/03. These data were also included in the following analysis. The results of the BST study are presented in Section 2.3.3.

The bacteria data collected at each VADEQ monitoring station are summarized in Table 2.3. Time-series fecal coliform bacteria (FC) data for VADEQ and Page County Water Quality Advisory Committee stations are presented in Figures 2.4 through 2.8.

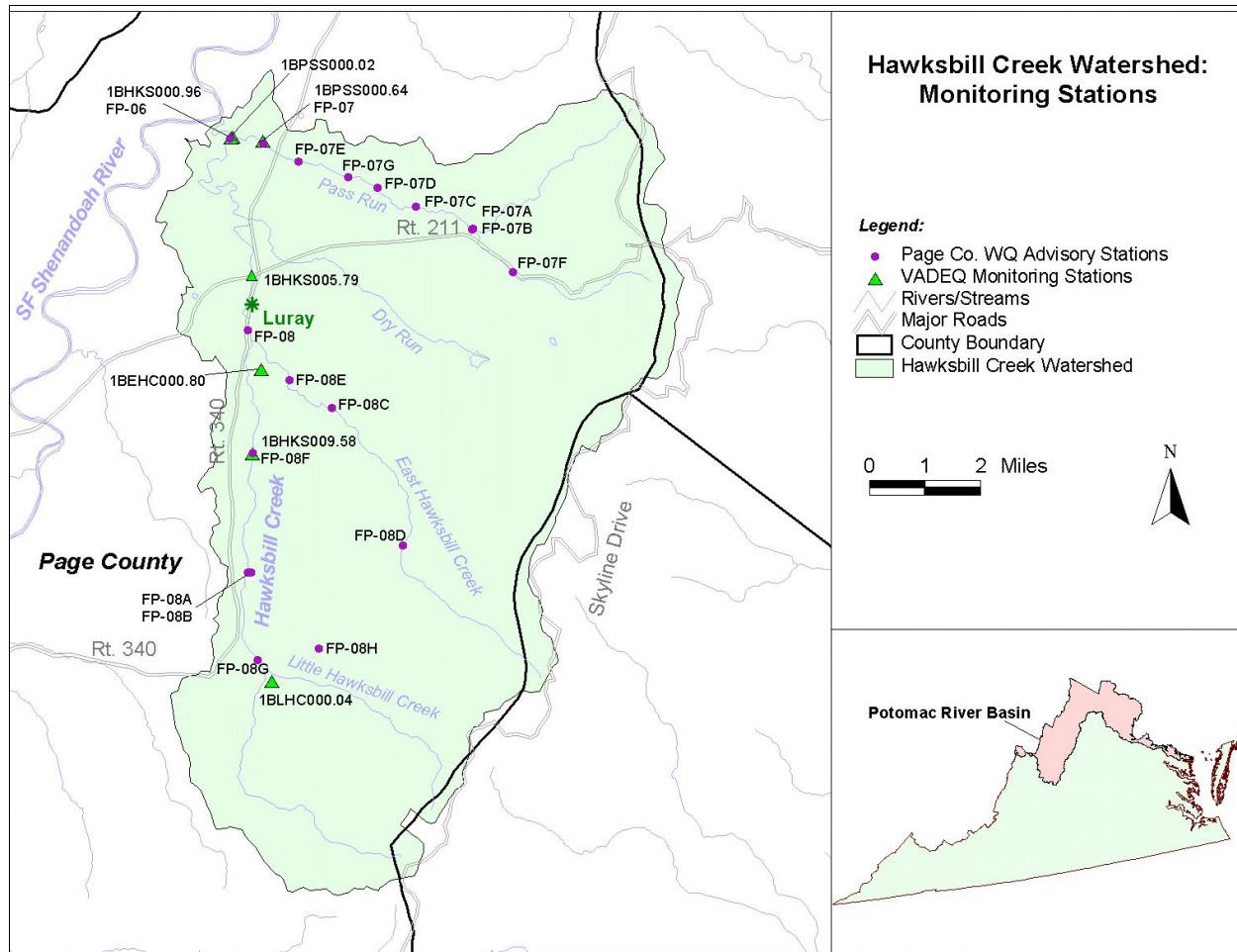


Figure 2.3 Location of Hawksbill Creek monitoring stations

Table 2.3 Bacteria monitoring summary

Station	Date	Sample Type¹	Count	Min-Max	Instantaneous Criteria FC: 400 cfu EC: 235 cfu (% Violations)
1BHKS000.96 (Lower Hawksbill)	7/16/91 - 8/11/03	FC	135	20-8,000	28
	7/24/02 - 8/11/03	EC	14	15-360	14
1BHKS009.58 (Upper Hawksbill)	12/18/91 - 9/23/03	FC	43	50-6,100	47
	7/24/02 - 9/23/03	EC	14	50-2,000	50
1BPSS000.02 (Pass Run)	7/24/02 - 6/30/03	FC	11	50-375	0
	7/24/02 - 6/30/03	EC	11	20-260	18
1BPSS000.64 (Pass Run)	8/4/94 - 6/25/03	FC	31	25-8,000	55
	7/17/02 - 6/25/03	EC	6	10-800	50
1BEHC000.80 (East Hawksbill)	7/24/02 - 6/30/03	FC	12	25-1,600	25
	7/24/02 - 6/30/03	EC	12	20-1,300	25
1BLHC000.04 (Little Hawksbill)	7/24/02 - 6/30/03	FC	12	25-250	0
	7/24/02 - 6/30/03	EC	12	40-200	0
FP-06 (Lower Hawksbill)	9/25/98 - 12/14/01	FC	38	24-1,900	12
FP-08 (Hawksbill Combined)	9/25/98 - 12/14/01	FC	38	20-4,750	53
FP-08F (Rt. 629)	2/11/00 - 12/14/01	FC	22	200-5,450	82
FP-08A (Rt. 631)	9/10/99 - 10/26/01	FC	24	26-5,040	33
FP-08G (Marksville Bridge)	2/11/00 - 12/14/01	FC	22	1-1,080	18
FP-07 (Pass Run downstream)	9/25/98 - 12/14/01	FC	36	39-9,000	58
FP-07E (Burner's Spring)	8/27/99 - 11/14/00	FC	14	13-1,125	21

TMDL Development for Hawksbill Creek

Station	Date	Sample Type ¹	Count	Min-Max	Instantaneous Criteria FC: 400 cfu EC: 235 cfu (% Violations)
FP-07G (Whispering Hill Rd.)	2/11/00 - 11/17/00	FC	9	14-1,950	33
FP-07D (Lyn-Mar Rd.)	8/27/99 - 12/14/01	FC	25	12-1,950	20
FP-07C (Kimball Rd.)	8/27/99 - 11/17/00	FC	26	4-2,450	8
FP-07A (Rocky Branch)	1/22/99 - 12/14/01	FC	32	3-2,150	22
FP-07B (Jewell Hollow)	5/7/99 - 12/14/01	FC	28	4 - 6,075	29
FP-07F (US 211)	11/5/99 - 12/14/01	FC	22	2-870	5
FP-08E (East Hawksbill Stonyman Rd.)	2/11/00 - 12/14/01	FC	22	58-4,250	73
FP-08C (East Hawksbill East Branch Rd.)	9/10/99 - 12/14/01	FC	26	4-2,450	8
FP-08D (East Hawksbill Cross Mountain Rd.)	9/10/99 - 12/1/00	FC	15	2-2,060	7
FP-08B (Chubb Run Rt. 611)	9/10/99 - 12/14/01	FC	24	100-16,600	88
FP-08H (Chubb Run Rt. 689)	2/11/00 - 12/1/00	FC	22	200-5,450	82

¹ Sample type: FC = Fecal Coliform Bacteria, EC = *E. coli*

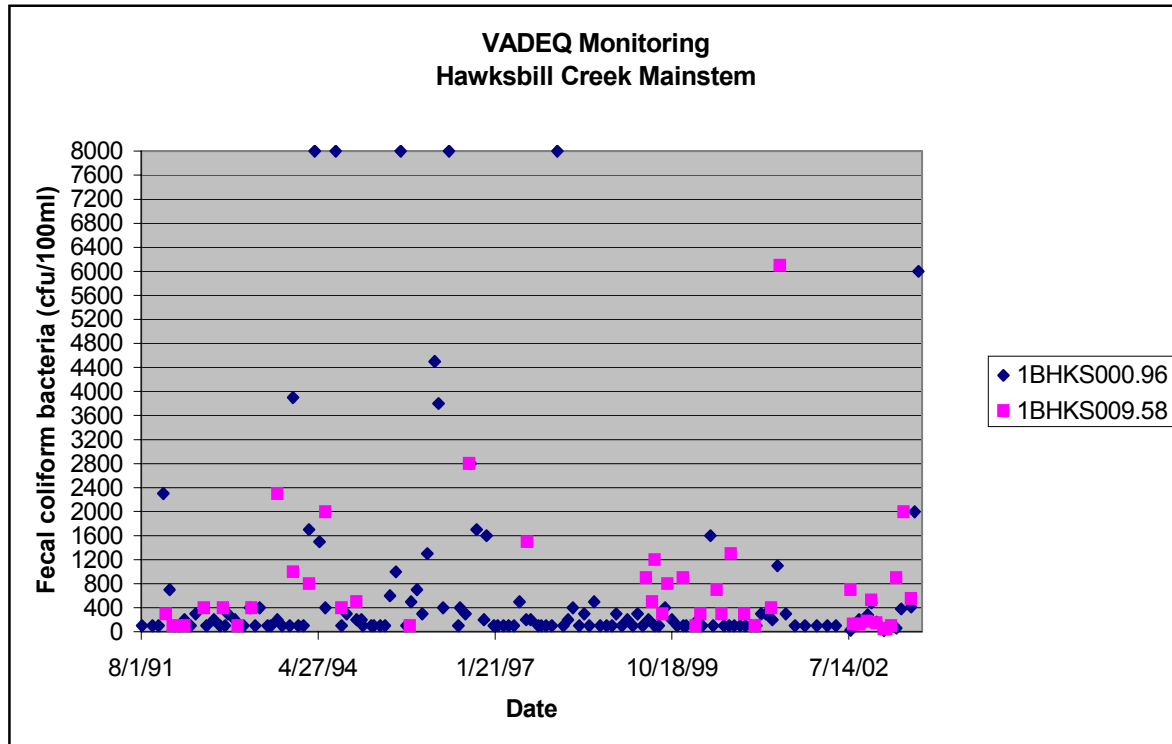


Figure 2.4 VADEQ FC bacteria data - mainstem stations

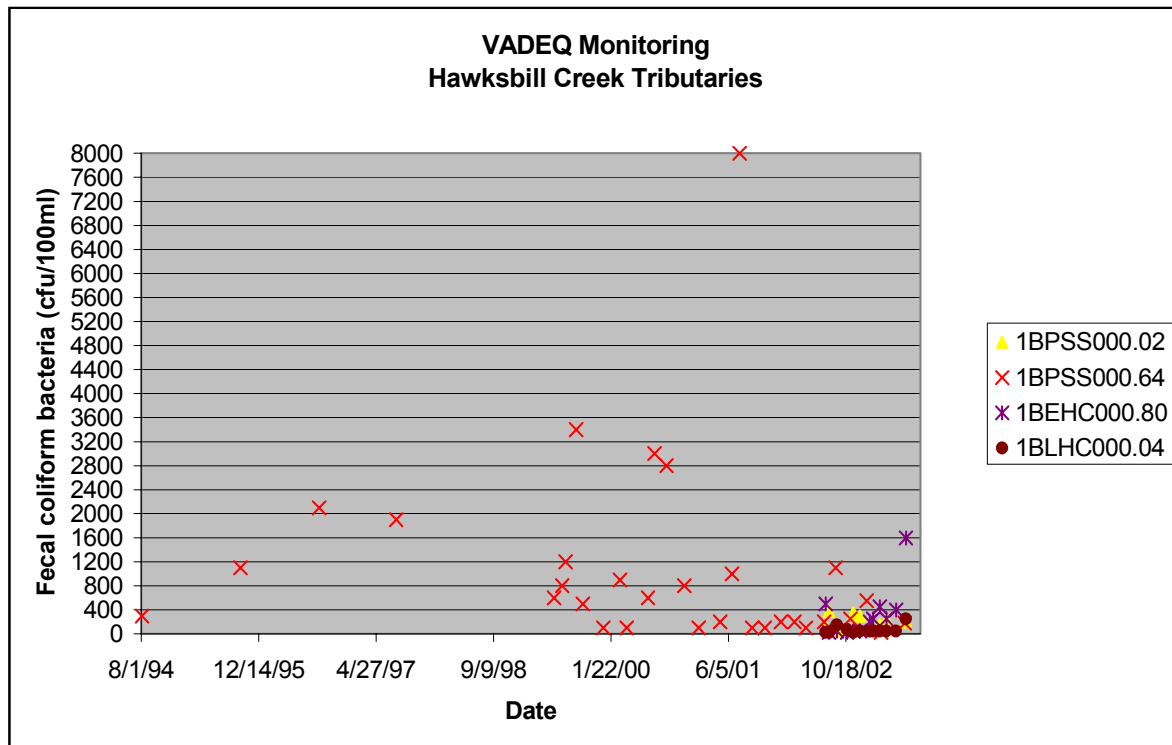


Figure 2.5 VADEQ FC bacteria data - tributary stations

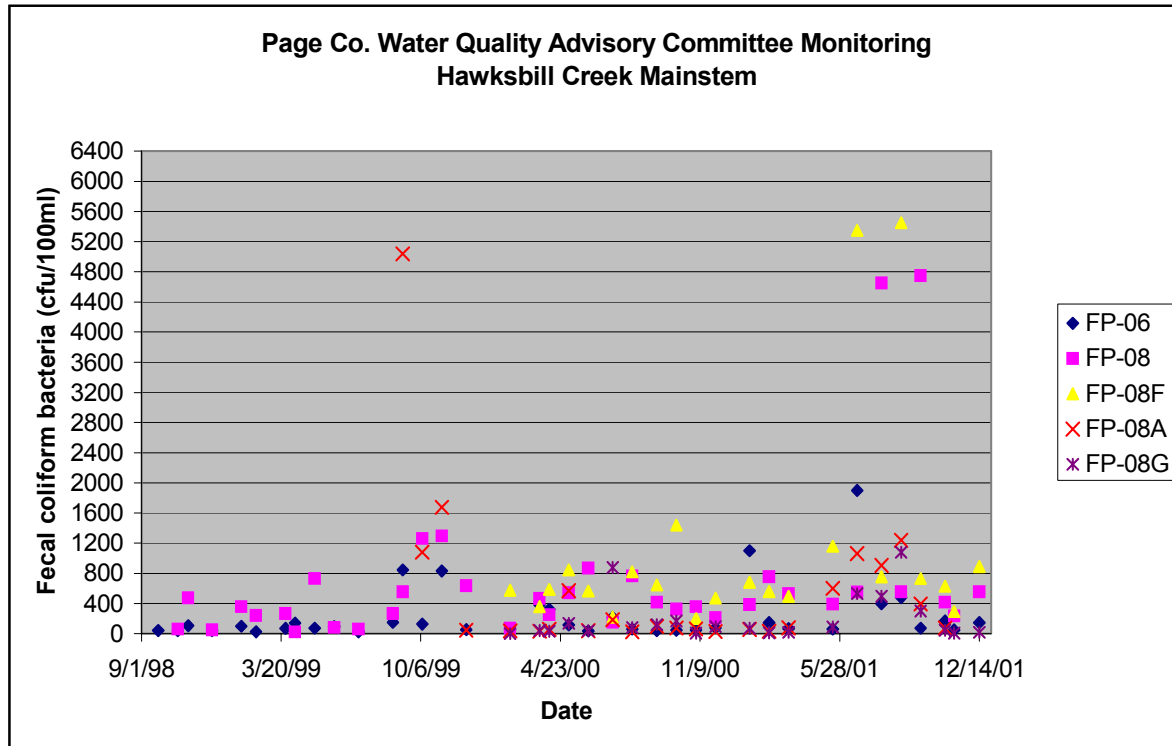


Figure 2.6 Page County FC bacteria data - mainstem stations

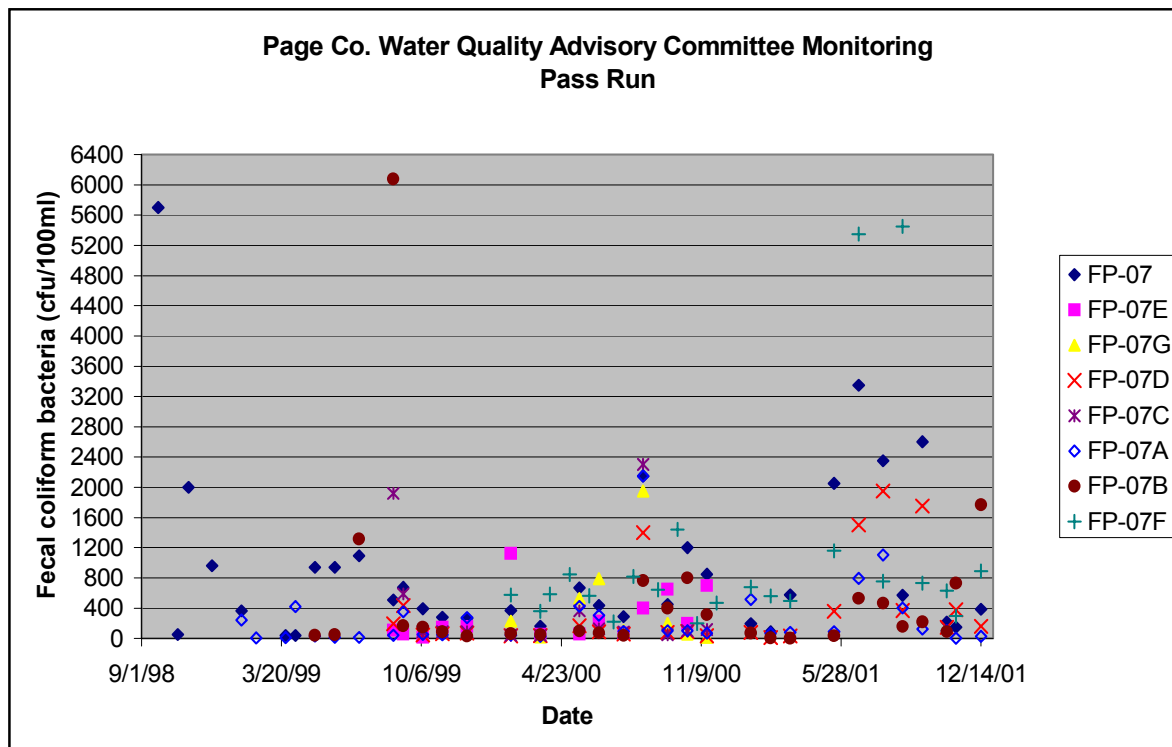


Figure 2.7 Page County FC bacteria data - Pass Run stations

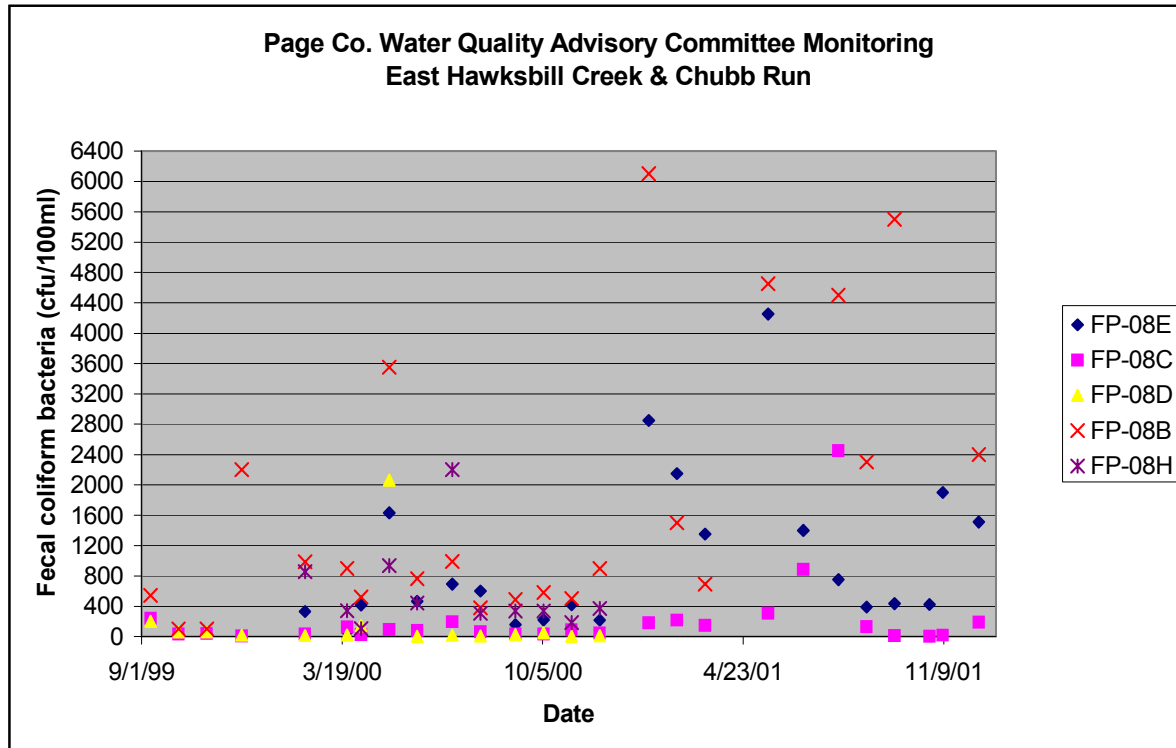


Figure 2.8 Page County FC bacteria data - East Hawksbill / Chubb Run stations

Of particular note is the number of DEQ samples that had a fecal count of 8,000 cfu/100 ml. The upper limit of laboratory analysis was typically 8,000 cfu/100 ml, depending on collection date. Therefore, many of these samples likely represent concentrations much higher than these limits. The percent violation analysis and the number of extremely high concentrations provide insight into the magnitude of the fecal contamination problems in these streams. Violations occurred in all flow regimes.

2.3.3 Bacteria Source Tracking (BST)

VADEQ collected BST data at station 1BHKS000.96 for a period of one year from September 5, 2002 through August 5, 2003 (12 monthly samples) to help identify the predominant sources of bacteria in the watershed (Table 2.4). Fecal coliform bacteria and *E. coli* concentrations were measured and the Antibiotic Resistance Analysis (ARA) methodology was used to determine the likely sources of bacteria in each sample. This methodology provides information on the presence or absence of human, pet, livestock, and wildlife sources in the watershed. No information was provided for upstream areas of the watershed.

Table 2.4 BST results for station 1BHKS000.96

Date	Fecal concentration (cfu/100ml)	<i>E. coli</i> concentration (cfu/100ml)	Wildlife (%)	Human (%)	Livestock (%)	Pets (%)
9/9/02	200	62	25	0	54	21
10/28/02	280	73	25	0	58	17
11/19/02	480	300	38	0	45	17
12/17/02	160	100	25	0	71	4
1/28/02	20	15	0	0	0	100
2/11/03	80	59	60	0	5	35
3/11/03	90	62	21	8	17	54
4/8/03	60	48	17	0	70	13
5/6/03	380	98	17	0	50	33
6/30/03	410	120	46	0	33	21
7/21/03	2,000	360	21	0	71	8
8/11/03	6,000	220	67	4	29	0

* bold values were statistically significant

SECTION 3

SOURCE ASSESSMENT - BACTERIA

Point and nonpoint sources of bacteria in the Hawksbill Creek watershed were considered in TMDL development. The source assessment was used as the basis of model development and analysis of TMDL allocation options. A variety of information was used to characterize sources including, agricultural and land use information, water quality monitoring and point source data, GIS coverages, past TMDL studies, literature sources, and other information. Procedures and assumptions used in estimating bacteria loads are described in the following sections.

3.1 Assessment of Nonpoint Sources

Agricultural runoff, wildlife, and past combined sewer overflows (CSOs) are listed as possible sources of bacteria, according to the 2002 303(d) Fact Sheet for Hawksbill Creek. Nonpoint sources of bacteria can include failing septic systems and leaking sewer lines, straight pipes, livestock (including manure application loads), wildlife, and domestic pets. The representation of the following sources in the model is discussed in Section 4.

3.1.1 Septic Systems and Straight Pipes

Residential septic systems treat human waste using a collection system that discharges liquid waste into the soil through a series of distribution lines that comprise the drain field. Fecal coliform bacteria naturally die-off as the effluent percolates through the soil to the groundwater. These systems effectively remove fecal coliform bacteria when properly installed and maintained.

A septic system failure occurs when there is a discharge of waste to the soil surface where it is available for washoff into surface waters. Failing septic systems can deliver high bacteria loads to surface waters, depending on the proximity of the discharge to a stream and the timing of rainfall events. Septic system failures typically occur in older systems that are not adequately maintained with periodic sewage pump-outs.

An estimated 4,858 people live in houses with a septic system or other means of sewage disposal (e.g., straight pipe) in the Hawksbill Creek watershed, as determined using the following methods. U.S. Census block-group data for Year 2000 were used to estimate the population served by sewer systems, septic systems, and other means (Census 2000). The septic population was determined based on the area of the Hawksbill Creek watershed that is located within each census block-group.

The number of failing septic systems was estimated using a failure rate of 4% based on information provided by the Virginia Department of Health (Kelly Vanover, VDH, pers. comm. 2004). A fecal coliform bacteria concentration of 10^5 cfu/100mL and a septic system waste flow of 70 gallons/person/day was used to estimate the contribution from failing septic systems to surface waters (Metcalf and Eddy, Inc. 1991). In some cases, human waste is directly deposited into surface waters from houses without septic systems. These “straight pipes” and other illicit discharges are illegal under Virginia regulations. Houses with straight pipes are typically older structures that are located in close proximity to a stream. The population served by straight pipes was assumed to be 0.5% of the septic population in the watershed (Kelly Vanover, VDH, pers. comm. 2004). Houses considered to have a normal functioning septic system were assumed to have a negligible contribution of fecal coliform bacteria to surface waters.

3.1.2 Livestock

Animal population estimates for poultry (chickens and turkeys) were based on combined animal feeding operation (CAFO) data for the Hawksbill Creek watershed provided by the Virginia Department of Conservation and Recreation (VADCR) (Table 3.1). Livestock population data for beef cattle, horses and sheep/lambs were obtained from the 1997 Virginia Agricultural Census data for Page County (VASS 1997). For the 1997 Agricultural Census data, a weighted average was used to estimate the population of each livestock species based on the percentage of pasture/hay land in the watershed (Table 3.1). Population estimates for goats were based on discussions with a local goat farmer. In addition, a meeting was held with local agricultural stakeholders that live in the watershed on October 9, 2003 to make necessary adjustments to livestock population estimates, grazing activities, manure application rates, and other agricultural data. Other livestock animals had very small populations as compared to the major livestock species listed in the table; therefore, the bacteria loads from these animals were assumed to be negligible.

Table 3.1 Livestock population estimates

Livestock Species	Hawksbill Creek Population
Beef Cattle	4,023 (1,000 confined)
Dairy Cattle	25 (all confined)
Horses	121
Hogs/Pigs	307
Sheep/Lambs	406
Chickens (pullets, layers, and broilers)	2,645,800
Turkeys	49,500
Goats	400

Bacteria produced by livestock can be deposited on the land, directly deposited in the stream (as is common when grazing animals have stream access), manually applied to cropland and other agricultural lands as fertilizer, or contributed to surface waters through illicit discharges from animal confinement areas. Bacteria deposited on the land, either directly or through manure application, are available for washoff into surface waters during rainfall events. There are no known illicit discharges of animal waste in the watershed.

Grazing animals, such as beef and dairy cattle, typically spend portions of the day confined to loafing lots, grazing on pasture lands, and watering in nearby streams. The percentage of time spent in each area effects the relative contribution of bacteria loads to the stream. The amount of time beef and dairy cattle spend in or near streams primarily depends on time of year and the availability of stream access and off-stream watering facilities. Estimates of the amount of time cattle spend in these different areas were based on information gained from the October 9, 2003 meeting with local farmers in the watershed. Cattle data are presented in Tables 3.2 and 3.3. Horse and sheep estimates were based on similar past TMDL studies. Horses were assumed to spend the majority of each day in pasture (75% of the day in pasture during March - November, 25% in December - February). Sheep were assumed to be in pasture 100% of the time.

Table 3.2 Non-Confined Beef Cattle - daily hours spent grazing, in confinement, and in streams

Month	Grazing (hours)	Loafing Lot - Confinement (hours)	Stream Access (hours)
January	23.8	0	0.25
February	23.8	0	0.25
March	23.8	0	0.25
April	23.8	0	0.25
May	23.8	0	0.25
June	23.5	0	0.5
July	23.5	0	0.5
August	23.5	0	0.5
September	23.8	0	0.25
October	23.8	0	0.25
November	23.8	0	0.25
December	23.8	0	0.25

Table 3.3 Confined Beef and Dairy Cattle - daily hours spent grazing, in confinement, and in streams

Month	Grazing (hours)	Loafing Lot - Confinement (hours)	Stream Access (hours)
January	0	24	0
February	0	24	0
March	0	24	0
April	0	24	0
May	0	24	0
June	0	24	0
July	0	24	0
August	0	24	0
September	0	24	0
October	0	24	0
November	0	24	0
December	0	24	0

Collected manure from livestock animals was applied to cropland and pasture in the Hawksbill Creek watershed based on estimates provided by local farmers at the October 9, 2003 stakeholder meeting. Beef cattle and poultry manure represent the primary sources of land-applied livestock waste. For the confined beef cattle population, the same fraction of manure collected throughout the year was applied each month. Manure collected from the small dairy cattle population was determined to be applied outside of the Hawksbill Creek watershed. Turkeys and chickens are confined to poultry houses and hogs are confined to feed lots in the watershed; therefore, the litter produced is manually applied to cropland and pasture. Discussions with local poultry producers indicate that approximately 1/3 of the litter produced is composted. After taking into account composting and the amount of litter that is typically exported, approximately 50% of the litter produced is applied to agricultural land in the Hawksbill Creek watershed. The application of collected manure for each species is presented in Tables 3.4 through 3.7. The manure is used to fertilize corn and other primary crops year-round. Tillage allows for the incorporation of fecal coliform bacteria that is applied to the soil surface. Based on field observations of cropland in the watershed, it was assumed that 25% of the manure that was applied was incorporated into the soil, resulting in 75% of the fecal coliform bacteria load being available for washoff.

Table 3.4 Beef Cattle - Fraction of the annual manure application that is applied each month

Month	Livestock Manure Fraction Applied
January	0.083
February	0.083
March	0.083
April	0.083
May	0.083
June	0.083
July	0.083
August	0.083
September	0.083
October	0.083
November	0.083
December	0.083

Table 3.5 Horses, Hogs, Goats - Fraction of the annual manure application that is applied each month

Month	Livestock Manure Fraction Applied
January	0
February	0
March	0.075
April	0.1575
May	0.1335
June	0.1335
July	0.1335
August	0.1335
September	0.1575
October	0.075
November	0
December	0

Table 3.6 Poultry - Fraction of the annual manure application that is applied each month

Month	Livestock Manure Fraction Applied
January	0
February	0.01
March	0.3
April	0.25
May	0.05
June	0.05
July	0.02
August	0.02
September	0.1
October	0.1
November	0.1
December	0

Fecal coliform bacteria production rates used for livestock species in the Hawksbill Creek watershed are listed in Table 3.7. A variety of sources were consulted to determine the appropriate daily fecal coliform bacteria production value for each species, including other valley TMDL studies and literature sources.

Table 3.7 Livestock fecal coliform bacteria production rates

Livestock Species	Daily Production (cfu/animal/day)	Primary Sources
Beef cattle	4.46×10^{10}	ASAE 1998, USGS 2002
Dairy cattle	3.90×10^{10}	ASAE 1998, USGS 2002
Chickens	6.75×10^7	ASAE 1998, USGS 2002
Turkeys	9.30×10^7	ASAE 1998, USGS 2002
Hogs/Pigs	1.08×10^{10}	ASAE 1998, USGS 2002
Sheep	1.96×10^{10}	ASAE 1998, USGS 2002
Horses	5.15×10^{10}	ASAE 1998, USGS 2002
Goats (based on the daily production rate for sheep)	5.59×10^{10}	ASAE 1998, USGS 2002

3.1.3 Wildlife

Wildlife species in the watershed were identified through consultation with the Virginia Department of Game and Inland Fisheries (VDGIF). The predominant species include ducks, geese, deer, beaver, raccoon, and muskrat. The population of each wildlife species was estimated using the population density per square mile of habitat area and the total area of suitable habitat in the watershed (Table 3.8). Habitat areas were determined using GIS and the watershed land use coverage (MRLC). The density and habitat assumptions used to estimate the population of each wildlife species were updated based on information provided by state and local VDGIF personnel. Population estimates and the defined habitat of each species in the Hawksbill Creek watershed are listed in Table 3.9. Percent time spent in streams was adjusted based on recent valley TMDL studies and watershed model calibration data.

Table 3.8 Wildlife population density by land use (# animals per square mile of habitat)

Land Use	Ducks		Geese		Deer	Beaver	Raccoon	Muskrat
	Summer	Winter	Summer	Winter				
Cropland	30	40	50	70	0	5	2.5	320
Pasture/Hay	30	40	50	70	35	5	2.5	160
Forest	10	20	0	0	35	10	5	160
Built-Up (Urban)	30	40	50	70	0	5	2.5	320

Table 3.9 Wildlife habitat descriptions, population estimates, and percent of time spent in streams

Wildlife Species	Habitat Description	# of Animals	% in Streams
Ducks	100 meter buffer around perennial streams for all land uses	140 in summer 213 in winter	2.5%
Geese	100 meter buffer around perennial streams for Pasture/Hay, Cropland, and Built-Up	168 in summer 236 in winter	2.5
Deer	25 deer/mi ² for Pasture and Forest	2,879 year-round	1
Beaver	20 meter buffer around perennial streams for all land uses	12 year-round	50
Raccoon	0.5 mile buffer around perennial streams for all land uses	195 year-round	1
Muskrat	20 meter buffer around perennial streams for all land uses	258 year-round	2.5

As with grazing livestock, wildlife deposit on the land and directly to surface waters. The percentage of fecal coliform bacteria that was directly deposited to surface waters was estimated based on the habitat of each species. The remaining fecal coliform load was applied to the upland land uses,

according to the total area of each land use within established habitat areas. The typical fecal coliform density for each wildlife species was used to calculate fecal coliform bacteria loads (Table 3.10).

Table 3.10 Fecal coliform bacteria production rates for wildlife species

Wildlife Species	Daily Production (cfu/animal/day)	Primary Sources
Ducks	7.35×10^9	ASAE 1998, USGS 2002
Geese	7.99×10^8	USGS 2002
Deer	3.47×10^8	VADEQ 2001
Beaver	2.0×10^5	VADEQ 2000
Raccoon	5.0×10^9	VADEQ 2001
Muskrat	2.5×10^7	VADEQ 2001

3.1.4 Domestic Pets

Domestic pets were also considered in source assessment and watershed modeling. The bacteria contribution from domestic pets was represented by the waste deposited by dogs. The contribution from other pets was considered negligible. Housing estimates were used to determine the number of dogs in the watershed (Census 2000). Based on the assumption of one dog per household, the number of dogs in the Hawksbill Creek watershed was estimated to be approximately 2,156. The fecal coliform concentration in dog waste is 1.85×10^9 cfu/100mL (Mara and Oragui 1981).

3.2 Assessment of Point Sources

Point sources, such as municipal sewage treatment plants, can contribute fecal coliform bacteria loads to surface waters through effluent discharges. These facilities are permitted through the Virginia Pollutant Discharge Elimination System (VPDES) program that is managed by VADEQ. There are currently three point source permits in the Hawksbill Creek watershed that discharge bacteria (Table 3.11). The bacteria load for each facility was calculated based on the permitted flow and the applicable *E. coli* limit (126 cfu/100ml, geometric mean concentration). * Note that there are additional permitted facilities in the Hawksbill Creek watershed that do not discharge bacteria and were not included in the *E. coli* TMDL for Hawksbill Creek.

Table 3.11 VPDES permitted facilities in the Hawksbill Creek watershed

Permit	Facility	Receiving Stream
VA0024406	Big Meadows STP	Hawksbill Creek
VA0024422	Skyland Developed Area	East Hawksbill Creek, U.T.
VA0062642	Luray STP	Hawksbill Creek

SECTION 4

WATERSHED MODELING

Establishing the relationship between the in-stream water quality targets and source loadings is a critical component of TMDL development. It allows for evaluation of management options that will achieve the desired source load reductions. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. The objective of this section is to present the approach taken to develop the linkage between sources and in-stream response for the development of bacteria TMDLs for Hawksbill Creek.

4.1 Modeling Framework Selection

Selection of the appropriate approach or modeling technique required consideration of the following:

- Expression of water quality criteria
- Dominant processes
- Source Integration
- Scale of analysis
- Efficient TMDL scenario evaluation

The applicable criteria for bacteria are presented in Section 1. Numeric criteria require evaluation of magnitude, frequency, and duration. *E. coli* water quality criteria are presented as both an instantaneous maximum standard (235 cfu/100ml) and a geometric mean standard (126 cfu/100ml, minimum of two samples collected within a calendar month period). The approach or modeling technique must permit representation of in-stream concentrations under a variety of flow conditions in order to evaluate critical periods for comparison to these criteria.

The appropriate approach must also consider the dominant processes regarding pollutant loadings and in-stream fate. For the Hawksbill Creek watershed, primary sources contributing to bacteria impairments include an array of nonpoint or diffuse sources as well as discrete direct inputs to the stream either by permitted point source discharges or animal direct deposition to the streams. Loading processes for nonpoint sources or land-based activities are typically rainfall-driven and thus relate to surface runoff and subsurface discharge to a stream.

Key in-stream factors that must be considered include routing of flow, dilution, transport, and fate (decay or transformation) of pathogens. In the stream systems of the Hawksbill Creek watershed,

the primary physical process affecting the transport of bacteria is the die-off rate.

Scale of analysis and waterbody type must also be considered in the selection of the overall approach. The approach should have the capability to evaluate watersheds at multiple scales, and be able to adequately represent the spatial distribution of sources and the delivery processes whereby bacteria are delivered throughout the stream network.

Based on the considerations described above, analysis of the monitoring data, review of the literature, characterization of the bacteria sources, the need to represent source controls to individual sources, and previous modeling experience, the Loading Simulation Program C++ (LSPC) was selected to represent the source-response linkage in the Hawksbill Creek watershed. LSPC, the primary watershed modeling system for the EPA TMDL Toolbox, is currently maintained by the EPA Office of Research and Development in Athens, GA (<http://www.epa.gov/athens/wwqtsc>).

Note that the model predicts fecal coliform bacteria concentrations. *E. coli* bacteria concentrations are estimated using the VADEQ fecal coliform bacteria/*E. coli* translator in order to compare the results to the instantaneous and geometric mean criteria for *E. coli* and develop TMDLs (VADEQ 2003).

4.1.1 Loading Simulation Program C++ (LSPC) Overview

LSPC is a watershed modeling system that includes streamlined Hydrologic Simulation Program Fortran (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land as well as a simplified stream transport model. A key data management feature of this system is that it uses a Microsoft Access database to manage model data and weather text files for driving the simulation. The system also contains a module to assist in TMDL calculation and source allocations. For each model run, it automatically generates comprehensive text-file output by subwatershed for all land-layers, reaches, and simulated modules, which can be expressed on hourly or daily intervals. Output from LSPC has been linked to other model applications such as EFDC, WASP, and CE-QUAL-W2. LSPC has no inherent limitations in terms of modeling size or model operations. The Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel.

LSPC was designed to facilitate data management for large-scale or complex watershed modeling applications. The model has been successfully used to model watershed systems composed of over 1,000 subwatersheds at a National Hydrography Dataset (NHD) stream-segment scale. The system is also tailored for source representation and TMDL calculation. The LSPC GIS interface, which is compatible with ArcView shapefiles, acts as the control center for launching watershed model scenarios. This stand-alone interface easily communicates with both shapefiles and an underlying Microsoft Access database, but does not directly rely on either of these main programs. Therefore, once a watershed application is created, it is easily transferable to users who may not have ArcView

or MS Access installed on their computers.

Selected HSPF modules were re-coded in C++ and included in the LSPC model. LSPC's algorithms are identical to those in HSPF. Table 4.1 presents the modules from HSPF that are incorporated in LSPC. The user may refer to the Hydrologic Simulation Program FORTRAN User's Manual for a more detailed discussion of simulated processes and model parameters (Bicknell et al. 1996).

Table 4.1 HSPF modules available and supported in the LSPC watershed model

Simulation Type	HSPF Module	HSPF Module Description
Land Based Processes	PWATER	Water budget for pervious land
	IWATER	Water budget for impervious land
	SNOW	Incorporates snow fall and melt into water budget
	SEDMNT	Production and removal of sediment
	PWTGAS	Est. water temperature, dissolved gas concentrations
	IQUAL	Simple relationships with solids and water yield
	PQUAL	Simple relationships with sediment and water yield
In-stream Processes	HYDR ADCALC	Hydraulic behavior, pollutant transport
	CONS	Conservative constituents
	HTRCH	Heat exchange, water temperature
	SEDTRN	Behavior of inorganic sediment
	GQUAL	Generalized quality constituent

Meteorological Data Processing

Weather conditions are the driving force for watershed hydrology processes. For the simulation options selected for the Hawksbill Creek watershed model, the required parameters include hourly precipitation and hourly potential evapotranspiration. Precipitation is measured, while potential evapotranspiration is empirically computed using temperature and gage latitude. Table 4.2 below summarizes the weather data that were collected for the Hawksbill Creek watershed model. These data were obtained from the listed National Climatic Data Center (NCDC) meteorological stations.

Table 4.2 NCDC meteorological datasets compiled for Hawksbill Creek watershed model

Station ID	Timestep	Data Type	Station Name	Start Date	End Date	Elevation (ft)
VA2208	Hourly	Precipitation	Dale Enterprise	9/1/1978	12/31/2002	1400
WV6163	Hourly	Precipitation	Moorefield 1 SSE	5/1/1948	12/31/2000	890
VA8903	Hourly	Precipitation	Washington Dulles Intl	1/1/1984	12/28/2000	290
445096	Daily	Precipitation	Luray 5 E	8/1/1948	12/31/2002	1400
445096	Daily	Min Temperature	Luray 5 E	8/1/1948	12/31/2002	1400
445096	Daily	Max Temperature	Luray 5 E	8/1/1948	12/31/2002	1400

The Luray 5 E (445096) daily weather monitoring station is located in the Hawksbill Creek watershed. The nearest hourly stations are Dale Enterprise (VA2208), Moorefield 1 SSE (WV6163), and Washington Dulles International Airport (VA8913), which are approximately 30 miles SW of the watershed, 36 miles NW of the watershed, and approximately 55 miles NE of the watershed, respectively.

Daily minimum and maximum temperature between 1980 and 2002 were used to compute the potential evapotranspiration time-series. This process is described in greater detail in Section 4.1.2.

Of the four precipitation stations, Luray 5 E was the most representative of the watershed; however, the data collected at this station are daily. The Woodstock station was used for the period from 1980 to 1996 and the normal-ratio method (Dunn and Leopold 1978) was used to disaggregate the daily rainfall data to hourly values based on hourly rainfall distributions at two other stations. First, a composite hourly distribution was determined as a weighted average hourly time-series of the two nearby stations. Second, the daily values were distributed to the resulting hourly time-series, keeping the original rainfall volume intact. Also using the same methodology, missing or deleted intervals in the data were simultaneously patched using the normal-weighted hourly distributions at the two nearby stations. This entire process is described in greater detail in Section 4.1.3.

4.1.2 Computing Potential Evapotranspiration

Daily minimum and maximum temperature data between 1980 and 2002 from the Edinburg and Woodstock 2 NE stations were used to compute the potential evapotranspiration time-series. The Hamon method (1961) was used to compute evapotranspiration. The Hamon formula states that:

$$PET = CTS \times DYL \times DYL \times VDSAT \quad \text{Eqn 5.1}$$

where

<i>PET</i>	daily potential evapotranspiration (in)
<i>CTS</i>	monthly variable coefficient (a value of 0.0055 is suggested)
<i>DYL</i>	possible hours of sunshine, in units of 12 hours, computed as a function of latitude and time of year
<i>VDSAT</i>	saturated water vapor density (absolute humidity) at the daily mean air temperature (g/cm ³)

The formula to compute saturated water vapor density (*VDSAT*) states that:

$$VDSAT = \frac{216.7 \times VPSAT}{TAVC + 273.3} \quad \text{Eqn 5.2}$$

where

<i>VPSAT</i>	saturated vapor pressure at the air temperature
<i>TAVC</i>	mean daily temperature computed from daily min and max (Deg C)

The formula for saturation vapor pressure (*VPSAT*) states that:

$$VPSAT = 6.108 \times \exp\left(\frac{17.26939 \times TAVC}{TAVC + 273.3}\right) \quad \text{Eqn 5.3}$$

Finally, the daily *PET* values were disaggregated to hourly time-series values using a standard sine wave equation, over the daylight hours (*DYL*), which reaches its peak at noon of each day.

4.1.3 Patching and Disaggregating Rainfall Data

Unless the percent coverage is 100%, meaning that the weather station is always in operation and is accurately recording data throughout the specified time period, precipitation stations may contain various intervals of accumulated, missing, or deleted data. Missing or deleted intervals are periods over which either the rainfall station malfunctioned or the data records were somehow lost. Accumulated intervals represent cumulative precipitation over several hours, but the exact hourly distribution of the data is unknown.

To disaggregate the daily rainfall totals to hourly values, each day that rainfall is recorded is treated as an accumulated interval over the 24-hour period. The normal-ratio method (Dunn & Leopold 1978) was used to repair accumulated, missing, and deleted data intervals based on hourly rainfall patterns at nearby stations where unimpaired data is measured. The normal-ratio method estimates a missing rainfall value using a weighted average from surrounding stations with similar rainfall patterns according to the relationship:

$$P_A = \frac{1}{n} \left(\sum_{i=1}^n \frac{N_A}{N_i} P_i \right) \quad \text{Eqn 5.4}$$

where P_A is the impaired precipitation value at station A , n is the number of surrounding stations with unimpaired data at the same specific point in time, N_A is the long term average precipitation at station A , N_i is the long term average precipitation at nearby station i , and P_i is the observed precipitation at nearby station i . For each impaired data record at station A , n consists of only the surrounding stations with unimpaired data; therefore, for each record, n varies from 1 to the maximum number of surrounding stations (which in this case is 3). When no precipitation is available at the surrounding stations, zero precipitation is assumed at station A . The US Weather Bureau has a long established practice of using the long-term average rainfall as the precipitation normal. Since the normal ratio considers the long-term average rainfall as the weighting factor, this method is adaptable to regions where there is large orthographic variation in precipitation; therefore, elevation differences will not bias the predictive capability of the method. Figure 4.1 shows 20-water-year annual rainfall totals at the Luray 5 E station by water year.

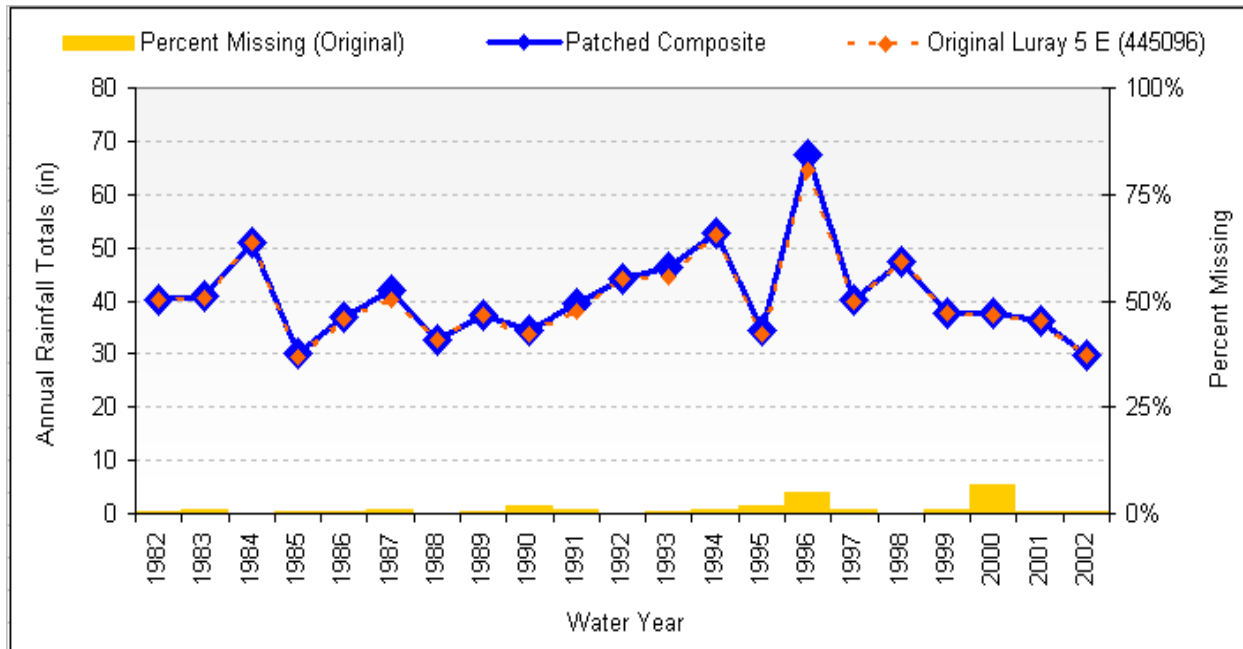


Figure 4.1 Total annual precipitation totals and daily quality at Luray 5 E before and after patching

4.2 Model Setup

LSPC was configured for the Hawksbill Creek watershed to simulate the watershed as a series of hydrologically connected subwatersheds. Configuration of the model involved subdivision of the Hawksbill Creek watershed into modeling units and continuous simulation of flow and water quality for these units using meteorological, land use, point source loading, and stream data. The watershed was subdivided into 28 subwatersheds to adequately represent the spatial variation in pathogen sources, watershed characteristics, hydrology, and the location of water quality monitoring and streamflow gaging stations. The delineation of subwatersheds was based primarily on the location of streams and a topographic analysis of the watershed. Subwatersheds and primary streams are shown in Figure 4.2. The spatial division of the watershed allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watershed.

A continuous simulation period of thirteen years (1990-2002) was used in the hydrologic simulation analysis. This is due to the fact that the period of record for observation data spanned that time period. An important factor driving model simulations is precipitation data. The pattern and intensity of rainfall affects the build-up and wash-off of fecal coliform bacteria from the land into the streams, as well as the dilution potential of the stream.

Modeled land uses that contribute bacteria loads to the stream include pasture, cropland, urban land (including loads from failing septic systems and pets), and forest. Other sources, such as straight

pipes and livestock in streams, were modeled as direct sources in the model. Development of initial loading rates for land uses and direct sources are described in Section 4.3.

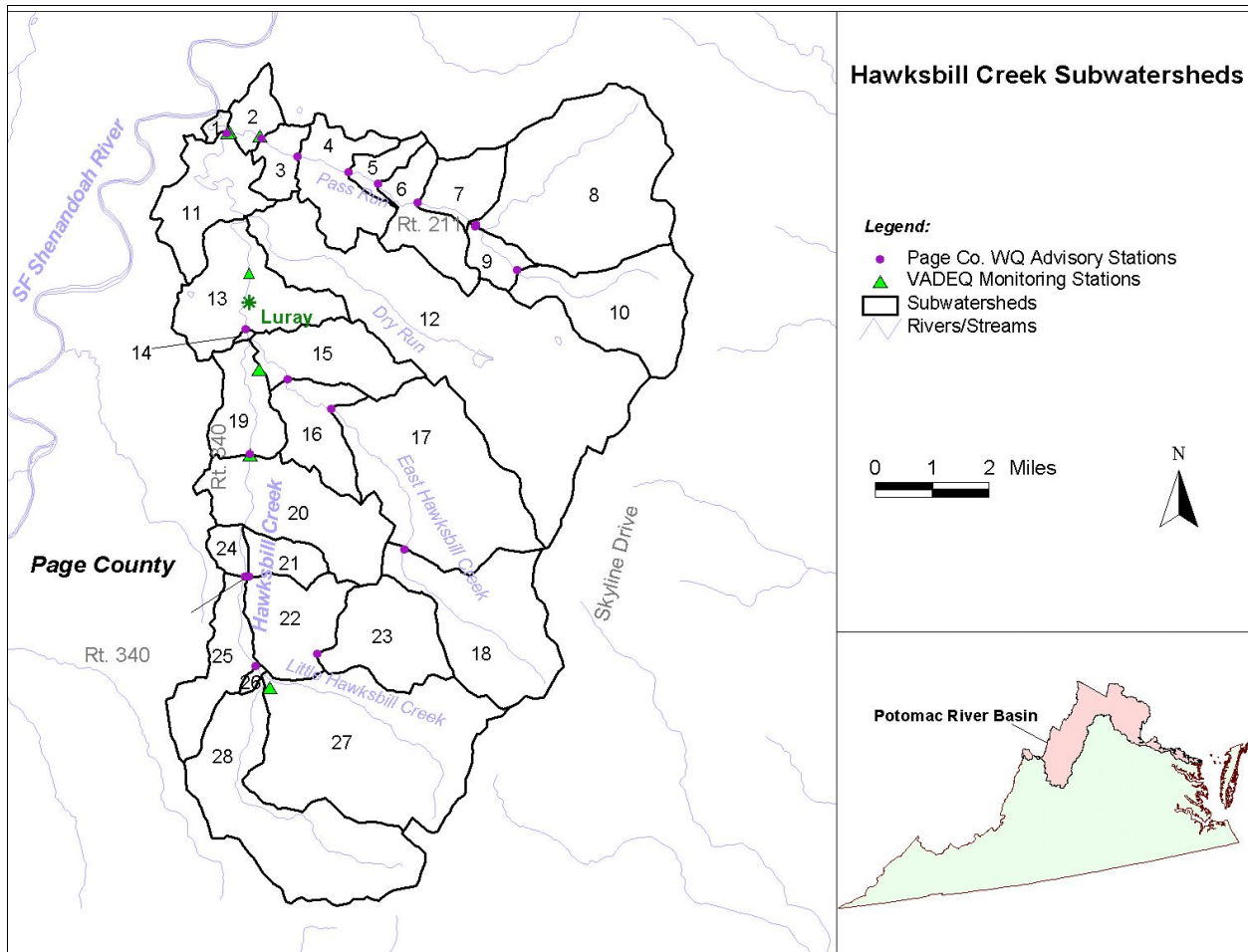


Figure 4.2 Hawksbill Creek subwatersheds

4.3 Source Representation

Both point and nonpoint sources were represented in the model for Hawksbill Creek. In general, the point sources were added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources were represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport vary with land use type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (e.g. animal defecation in

stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream.

4.3.1 Failing Septic Systems and Straight Pipes

Septic systems provide the potential to deliver bacteria loads to surface waters due to system failures caused by improper maintenance and/or malfunctions. The number of septic systems in each subwatershed was determined using U.S. Census Year 2000 block-group data for Page County, as described in Section 3.1.1 (Table 4.3). The percentage of urban land in each subwatershed was used to determine the septic population in each subwatershed. The number of failing septic systems was estimated using a failure rate of 4% based on information provided by the Virginia Department of Health (Kelly Vanover, VDH, pers. comm. 2004). Failing septic discharges contribute bacteria to the stream through runoff events (included in the urban land load).

In some cases, human waste is directly deposited into surface waters from houses without septic systems. The population served by straight pipes was assumed to be 0.5% of the septic population in the watershed (Kelly Vanover, VDH, pers. comm. 2004). These direct discharges are a constant source of bacteria to the receiving stream. Houses considered to have a normal functioning septic system were assumed to have a negligible contribution of fecal bacteria to surface waters.

Table 4.3 Total and failing septic population estimates (by subwatershed)

Subwatershed	Septic Population	Population served by failing septic systems
1	6	0
2	0	0
3	101	4
4	107	4
5	23	1
6	373	15
7	49	2
8	229	9
9	53	2
10	15	1
11	179	7
12	661	26
13	231	9

Subwatershed	Septic Population	Population served by failing septic systems
14	3	0
15	342	14
16	141	6
17	221	9
18	126	5
19	156	6
20	279	11
21	4	0
22	61	2
23	487	19
24	0	0
25	843	34
26	38	2
27	439	18
28	632	25
Total	4,858	194

* 29 people estimated to be using straight pipes

4.3.2 Livestock

Bacteria produced by livestock can be deposited on the land, directly deposited in the stream (as is common when grazing animals have stream access), manually applied to cropland and other agricultural lands as fertilizer, or contributed to surface waters through illicit discharges from animal confinement areas. Bacteria deposited on the land, either directly or through manure application, are available for washoff into surface waters during rainfall events. There are no known illicit discharges of animal waste in the watershed.

Animal population estimates for poultry (chickens and turkeys) were based on combined animal feeding operation (CAFO) data for the Hawksbill Creek watershed provided by VADCR (Table 3.1). Livestock population data for beef cattle, horses and sheep/lambs were obtained from the 1997 Virginia Agricultural Census data for Page County (VASS 1997). Population estimates for goats were based on discussions with a local goat farmer. In addition, a meeting was held with local agricultural stakeholders that live in the watershed on October 9, 2003 to make necessary adjustments to livestock population estimates, grazing activities, manure application rates, and other

agricultural data. Bacteria loads directed through each pathway were calculated by multiplying the bacteria density with the amount of waste expected through that pathway.

The livestock population for each subwatershed is presented in Table 4.4. The beef cattle, sheep, and horse subwatershed estimates were based on the amount of pasture land in each subwatershed.

Table 4.4 Livestock population by subwatershed

Sub-watershed	Beef Cattle (confined)	Dairy Cattle	Hogs	Sheep	Chickens (& Broilers)	Horses	Turkeys	Goats
1	12	0	0	1	0	0	0	0
2	90	0	7	9	0	3	0	2
3	104	0	0	10	0	3	0	3
4	265	25	0	27	178,000	8	7,500	7
5	41	0	0	4	0	1	0	1
6	86	0	0	9	25,000	3	0	2
7	16	0	0	2	0	0	0	0
8	95	0	0	10	0	3	0	2
9	5	0	0	0	0	0	0	0
10	24	0	0	2	0	1	0	1
11	264 (50)	0	0	27	120,000	8	0	7
12	507 (50)	0	0	51	171,000	15	0	13
13	235	0	0	24	0	7	0	6
14	3	0	0	0	0	0	0	0
15	266 (133)	0	0	27	60,000	8	8,000	7
16	229 (133)	0	100	23	186,000	7	0	6
17	344 (133)	0	0	35	484,000	10	0	309
18	29	0	0	3	92,000	1	0	1
19	225 (150)	0	100	23	106,000	7	34,000	5
20	271 (150)	0	100	27	213,000	8	0	6
21	71 (67)	0	0	7	0	2	0	2
22	215 (67)	0	0	22	99,000	6	0	5
23	113 (67)	0	0	11	202,000	3	0	3
24	63	0	0	6	0	2	0	2

Sub-watershed	Beef Cattle (confined)	Dairy Cattle	Hogs	Sheep	Chickens (& Broilers)	Horses	Turkeys	Goats
25	178	0	0	18	352,000	6	0	4
26	13	0	0	1	0	0	0	0
27	121	0	0	12	184,800	4	0	3
28	137	0	0	14	173,000	4	0	4

Liquid manure from confined animals is applied to cropland and hayland in the Hawksbill Creek watershed. Application rates vary monthly, with application primarily occurring during the spring and fall, according to the schedule presented in Section 3.1.2. Application of manure results in the accumulation of bacteria on the land surface. Therefore, bacteria accumulation rates are directly influenced by and based on the application rates of manure. To determine bacteria accumulation factors for the model, it was necessary to determine the amount present in manure. The fraction of manure application available for runoff was calculated by subtracting the amount typically incorporated into the soil matrix through tillage and natural processes (assumed 25% soil incorporation).

Beef and dairy cattle in streams were represented in the model as direct inputs (e.g. point sources) of bacteria. Using the fecal coliform bacteria production rates for beef and dairy cattle, the daily contribution from cattle in streams was calculated and then totaled by subwatershed depending on the population estimates of beef and dairy cattle watering in streams in each subwatershed (refer to Section 3.1.2). Bacteria contributions from cattle in streams were represented in the model using the total load delivered to the stream (#/day) and the flow rate at which it is delivered (cfs). The flow rate was determined using the amount of waste produced by beef and dairy cattle each day (lb/day) and an assumed density of the manure produced (lb/gal). Cattle in the stream were assumed to discharge at a constant rate.

Grazing animals also contribute bacteria to the land surface, which is available for washoff to surface waters during storm events. Beef and dairy cattle were the most abundant grazing animals in the watershed, as shown in Table 4.4. Sheep and horses represent the only other significant grazing livestock species in the Hawksbill Creek watershed. Cattle, sheep, and horses were distributed throughout pasture/hay areas in each subwatershed. Bacteria accumulation rates (#/acre/day) for each of these livestock species were calculated using subwatershed population estimates and the bacteria production rate established for each species.

4.3.3 Wildlife

The population of each wildlife species was estimated using the population density per square mile of habitat and the total area of suitable habitat in each subwatershed (Table 4.5). As with grazing

livestock, wildlife deposit manure on the land and directly to surface waters. The habitat and percentage of time each species typically spends in streams was used to determine the proportion of bacteria that was deposited on land versus directly to surface waters. Loads applied to the land (in each subwatershed) were distributed according to the total area of each land use type within the established habitat area of each species.

Table 4.5 Wildlife population by subwatershed

Subwatershed	Ducks		Geese		Deer	Beaver	Raccoon	Muskrat
	Summer	Winter	Summer	Winter				
1	2	3	2	3	5	<1	1	4
2	2	3	3	4	28	<1	2	3
3	2	3	3	5	27	<1	2	3
4	3	4	5	7	76	<1	4	4
5	2	3	3	4	20	<1	1	3
6	2	3	3	4	59	<1	4	4
7	3	4	3	5	48	<1	4	5
8	7	12	4	6	267	<1	19	19
9	2	3	1	1	26	<1	4	6
10	4	8	1	1	136	<1	11	12
11	7	11	8	11	88	<1	6	14
12	19	29	19	27	444	2	28	40
13	8	11	12	17	77	<1	6	13
14	0	1	1	1	1	<1	0	1
15	4	5	6	8	78	<1	2	4
16	4	5	6	8	65	<1	3	6
17	9	13	12	17	247	<1	13	15
18	6	10	2	3	172	<1	15	15
19	7	10	11	16	58	<1	5	9
20	4	6	7	10	133	<1	4	5
21	3	4	4	6	31	<1	1	4
22	7	9	12	16	79	<1	5	8
23	5	7	8	11	101	<1	7	5
24	4	5	6	8	16	<1	1	4

Subwatershed	Ducks		Geese		Deer	Beaver	Raccoon	Muskrat
	Summer	Winter	Summer	Winter				
25	6	8	9	12	59	<1	3	8
26	<1	1	1	1	3	<1	0	1
27	9	152	8	11	307	1	22	21
28	11	183	9	12	227	1	21	23
Total	140	212	168	235	2,879	12	194	258

4.3.4 Domestic Pets

Housing estimates were used to determine the number of pets in each Hawksbill Creek subwatershed (Census 2000). An assumption of one dog per household was used to calculate the pet population. Bacteria loading was applied to urban (built-up) lands and as direct deposition to the stream in each subwatershed.

4.4 Stream Characteristics

The channel geometry for the stream reaches in Smith Creek subwatersheds were based on the visual observation of stream channel configurations throughout the watershed and through an analysis of typical stream channel geometry values for these stream types. The stream segment length and slope values for each subwatershed were determined using GIS analysis of digitized streams and digital elevation models (DEMs).

4.5 Selection of a Representative Modeling Period

The selection of a representative modeling period is typically based on the availability of stream flow, weather, and water quality data for the modeled watershed. There is not a USGS flow gage located in the Hawksbill Creek watershed; therefore, the nearby Smith Creek watershed (Shenandoah and Rockingham Counties) was used as a reference watershed. Hourly flow discharge data were available from the USGS gage located in the lower portion of the watershed (USGS01632900) from 1980 through 2002. Monthly water quality data were collected by VADEQ on Hawksbill Creek during this same period; therefore, this time period was selected for modeling purposes. This time period represented varying climatic and hydrologic conditions, including dry, average, and wet periods that typically occur in the area. This was an important consideration because during dry weather and low flow periods, constant direct discharges primarily affect instream concentrations; however, during wet weather and high flow periods, surface runoff delivers nonpoint source bacteria loads to the stream, affecting instream concentrations more so than direct discharges.

4.6 Model Calibration Process

Hydrology parameters for the Hawksbill Creek watershed were based on the final parameters used in the Smith Creek reference watershed calibrated model. These parameters were used to establish the flow response and water balance in the Hawksbill Creek watershed, which has very similar geologic, soils, landuse, topography, and other key watershed attributes. Water quality calibration was based on comparing the fecal coliform bacteria data collected on Hawksbill Creek to the simulated concentrations.

The Smith Creek watershed model was calibrated using daily stream flow observations at data at USGS gage 01632900 for two selected periods during the 1990s. Model calibration years were selected using the following four criteria:

1. Completeness of the weather data available for the selected period.
2. Representation of low-flow, average-flow, and high-flow water years.
3. Consistency of selected period with key model inputs (i.e. land use coverage)
4. Quality of initial modeled versus observed data correlation

Based on a review of these four selection criteria, two calibration periods 1990 to 1991, and 1996 to 1997 were chosen as model calibration years. The MRLC land use coverage used in the model was developed during the mid 1990s, therefore, the selected calibration periods are consistent with this key model input. The model was validated for long-term and seasonal representation of hydrologic trends using a 13-year period (1990-2002).

Model calibration was performed using the error statistics criteria specified in HSPEXP, temporal comparisons, and comparisons of seasonal, high flows, and low flows. Calibration involved the adjustment of infiltration, subsurface storage, evapotranspiration, surface runoff, and interception storage parameters. After adjusting the appropriate parameters within acceptable ranges, good correlations were found between model results and observed data. Hydrology calibration and validation results for the Smith Creek reference watershed are shown in Figures 4.3 through 4.10 and Tables 4.6 through 4.9.

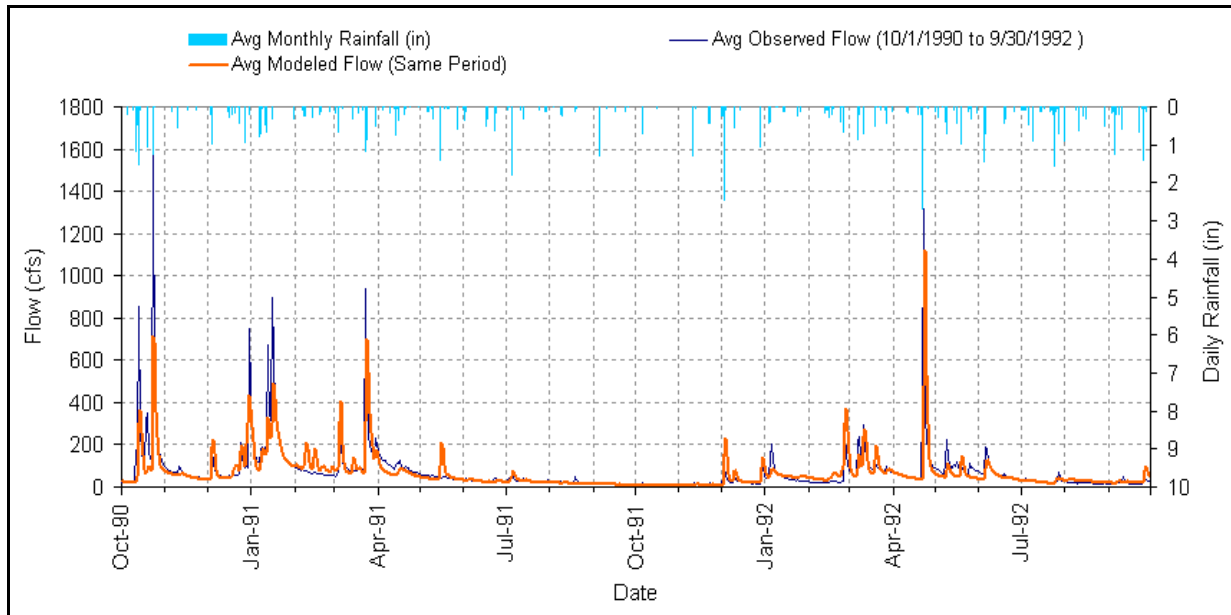


Figure 4.3 Daily flow calibration comparison for water years 1990-1991 at USGS 01632900

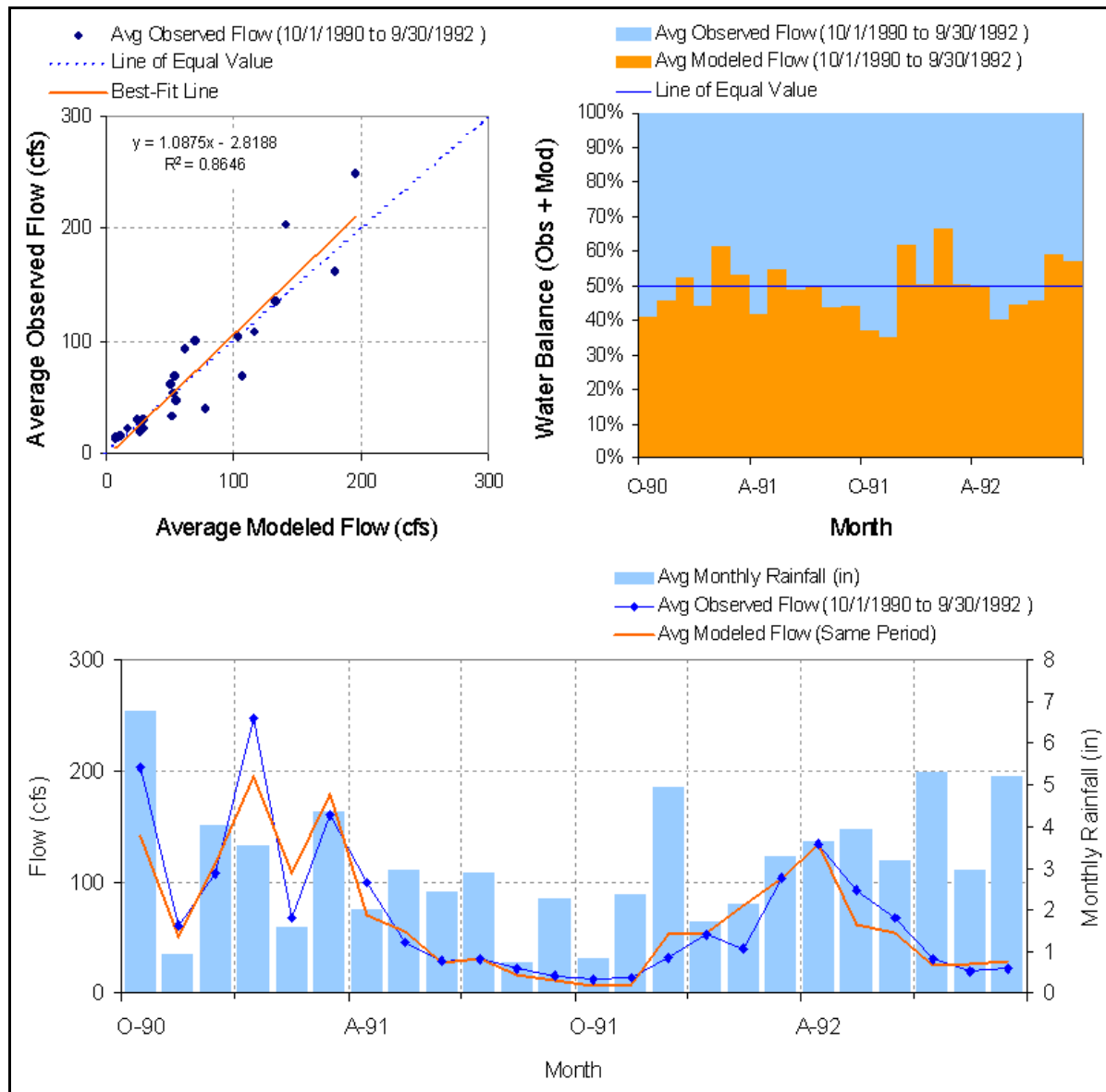


Figure 4.4 Monthly flow calibration comparison for water years 1990-1991 at USGS 01693200

Table 4.6 Error statistics for calibration water years 1990-1991

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 5		USGS 01632900 SMITH CREEK NEAR NEW MARKET, VA	
2-Year Analysis Period: 10/1/1990 - 9/30/1992 Flow volumes are (inches/year) for upstream drainage area		Shenandoah County, Virginia Hydrologic Unit Code 02070006 Latitude 38°41'36", Longitude 78°38'35" NAD27 Drainage area 93.20 square miles	
Total Simulated In-stream Flow:	9.96	Total Observed In-stream Flow:	10.45
Total of simulated highest 10% flows:	4.18	Total of Observed highest 10% flows:	4.49
Total of Simulated lowest 50% flows:	1.64	Total of Observed Lowest 50% flows:	1.65
Simulated Summer Flow Volume (months 7-9):	0.86	Observed Summer Flow Volume (7-9):	0.85
Simulated Fall Flow Volume (months 10-12):	2.31	Observed Fall Flow Volume (10-12):	2.66
Simulated Winter Flow Volume (months 1-3):	4.35	Observed Winter Flow Volume (1-3):	4.11
Simulated Spring Flow Volume (months 4-6):	2.44	Observed Spring Flow Volume (4-6):	2.85
Total Simulated Storm Volume:	3.79	Total Observed Storm Volume:	3.59
Simulated Summer Storm Volume (7-9):	0.14	Observed Summer Storm Volume (7-9):	0.14
<i>Errors (Simulated-Observed)</i>	<i>Error Statistics</i>	<i>Recommended Criteria</i>	
Error in total volume:	-4.98	10	
Error in 50% lowest flows:	-0.41	10	
Error in 10% highest flows:	-7.46	15	
Seasonal volume error - Summer:	1.12	30	
Seasonal volume error - Fall:	-14.91	30	
Seasonal volume error - Winter:	5.64	30	
Seasonal volume error - Spring:	-16.64	30	
Error in storm volumes:	5.42	20	
Error in summer storm volumes:	1.61	50	

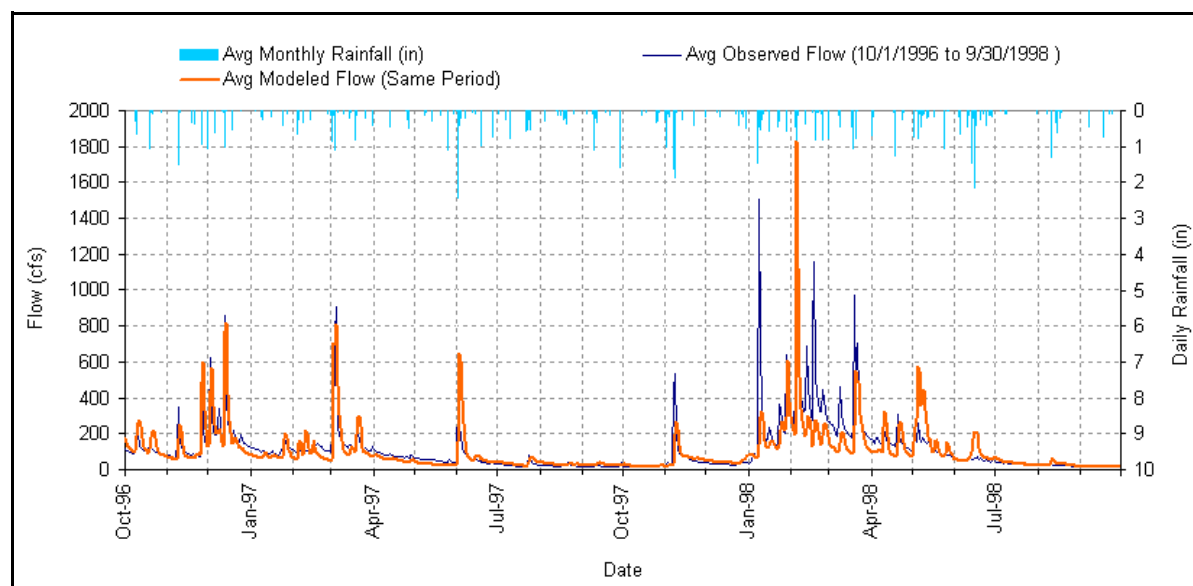


Figure 4.5 Daily flow calibration comparison for water years 1996-1997 at USGS 01632900

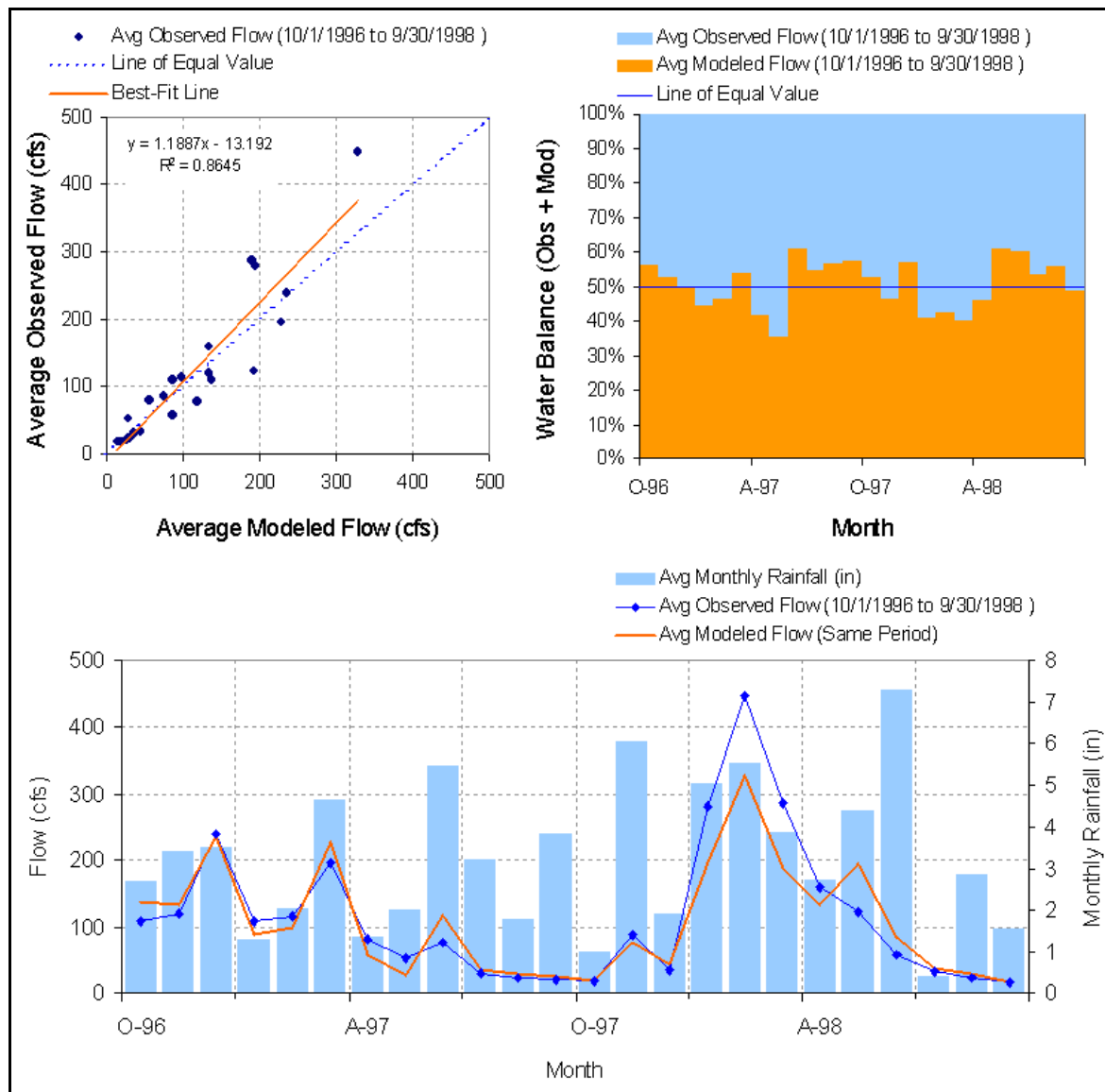


Figure 4.6 Monthly flow calibration comparison for water years 1996-1997 at USGS 01693200

Table 4.7 Error statistics for calibration water years 1996-1997

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 5 2-Year Analysis Period: 10/1/1996 - 9/30/1998 Flow volumes are (inches/year) for upstream drainage area		USGS 01632900 SMITH CREEK NEAR NEW MARKET, VA Shenandoah County, Virginia Hydrologic Unit Code 02070006 Latitude 38°41'36", Longitude 78°38'35" NAD27 Drainage area 93.20 square miles	
Total Simulated In-stream Flow:	15.47	Total Observed In-stream Flow:	16.43
Total of simulated highest 10% flows:	6.11	Total of Observed highest 10% flows:	6.50
Total of Simulated lowest 50% flows:	2.53	Total of Observed Lowest 50% flows:	2.44
Simulated Summer Flow Volume (months 7-9)	1.06	Observed Summer Flow Volume (7-9):	0.88
Simulated Fall Flow Volume (months 10-12):	3.96	Observed Fall Flow Volume (10-12):	3.71
Simulated Winter Flow Volume (months 1-3):	6.72	Observed Winter Flow Volume (1-3):	8.53
Simulated Spring Flow Volume (months 4-6):	3.74	Observed Spring Flow Volume (4-6):	3.31
Total Simulated Storm Volume:	5.94	Total Observed Storm Volume:	4.61
Simulated Summer Storm Volume (7-9):	0.14	Observed Summer Storm Volume (7-9):	0.10
<i>Errors (Simulated-Observed)</i>	<i>Error Statistics</i>	<i>Recommended Criteria</i>	
Error in total volume:	-6.19	10	
Error in 50% lowest flows:	3.41	10	
Error in 10% highest flows:	-6.40	15	
Seasonal volume error - Summer:	16.87	30	
Seasonal volume error - Fall:	6.27	30	
Seasonal volume error - Winter:	-26.94	30	
Seasonal volume error - Spring:	11.35	30	
Error in storm volumes:	22.34	20	
Error in summer storm volumes:	26.96	50	

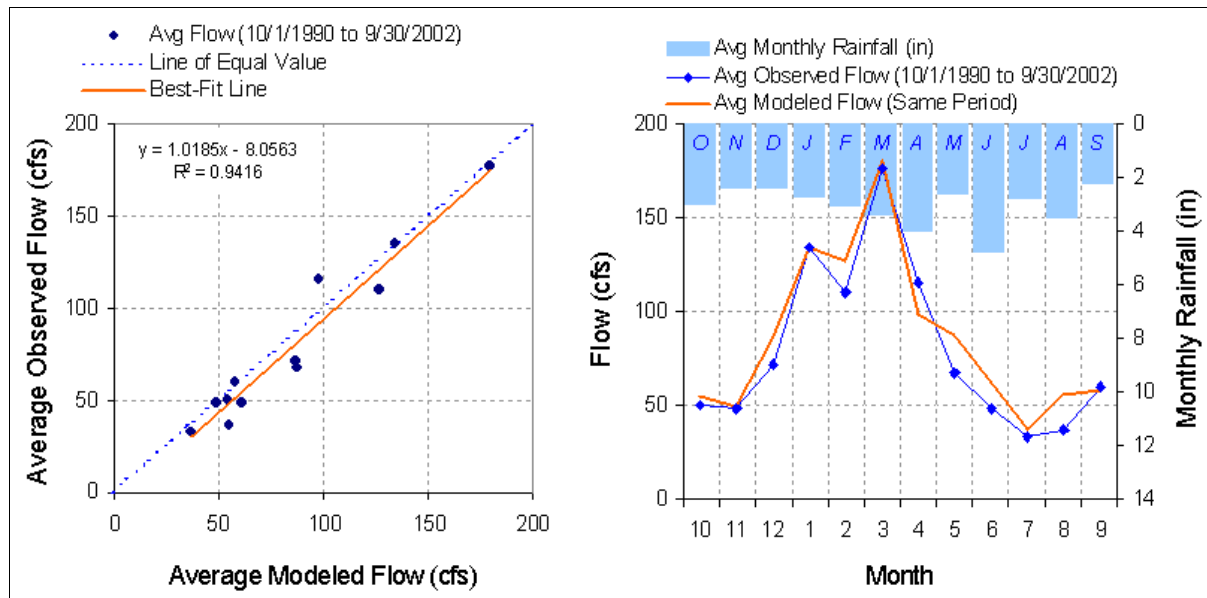


Figure 4.7 13-year annualized composite validation at USGS01632900 (Water Years 1990-2002)

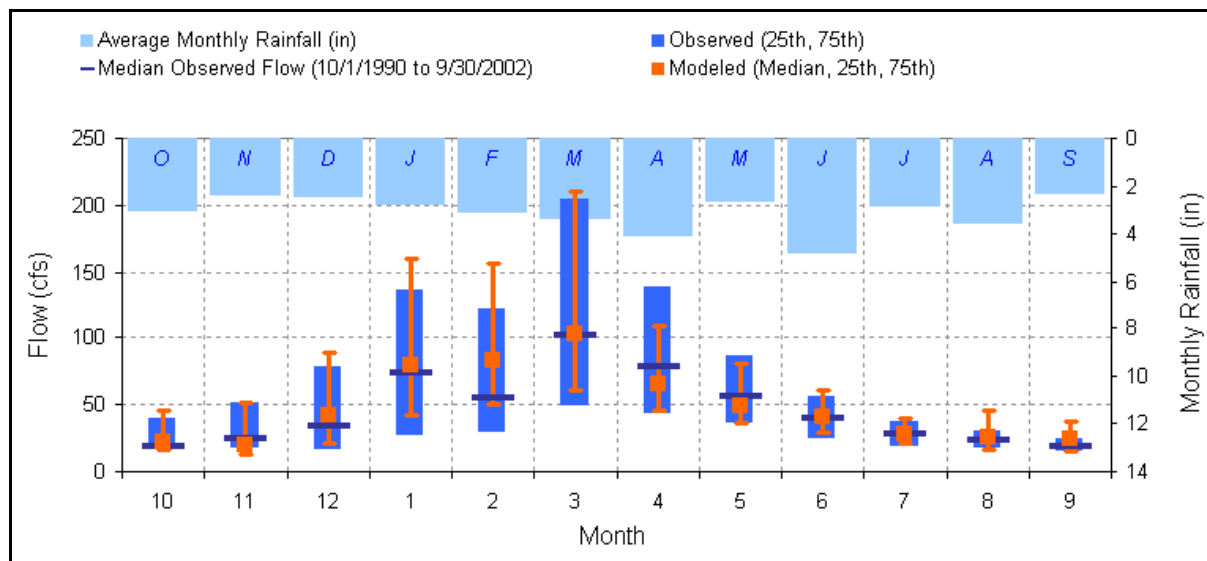


Figure 4.8 13-year annualized composite validation at USGS 01632900 for seasonal trend analysis (Water Years 1990-2002)

Table 4.8 Table of summary statistics for 13-year annualized validation at USGS 01632900

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	49.82	19.00	16.00	39.25	54.15	22.12	16.08	45.86
Nov	48.32	25.00	17.00	51.00	48.69	20.19	12.86	51.64
Dec	71.28	34.00	16.00	78.00	86.51	42.51	20.93	88.97
Jan	134.25	74.00	27.00	137.00	134.20	79.75	41.61	159.64
Feb	109.94	55.00	29.00	121.00	127.16	83.25	49.79	156.72
Mar	176.26	102.00	49.00	204.25	179.25	102.92	60.41	210.79
Apr	115.11	78.00	43.00	139.25	98.03	65.79	45.12	108.71
May	67.39	56.00	35.75	87.00	87.72	49.42	36.17	80.38
Jun	48.22	40.00	25.00	56.25	61.24	41.33	29.78	61.33
Jul	32.67	28.00	19.00	37.00	37.24	28.19	20.67	39.65
Aug	36.60	23.00	18.00	30.00	55.05	25.67	15.86	45.98
Sep	60.04	19.00	15.00	25.00	58.34	24.59	15.08	36.93

Table 4.9 Error statistics for validation period (Water Years 1990 to 2002)

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 5		USGS 01632900 SMITH CREEK NEAR NEW MARKET, VA	
12-Year Analysis Period: 10/1/1990 - 9/30/2002 Flow volumes are (inches/year) for upstream drainage area		Shenandoah County, Virginia Hydrologic Unit Code 02070006 Latitude 38°41'36", Longitude 78°38'35" NAD27 Drainage area 93.20 square miles	
Total Simulated In-stream Flow:	12.47	Total Observed In-stream Flow:	11.52
Total of simulated highest 10% flows:	5.83	Total of Observed highest 10% flows:	5.55
Total of Simulated lowest 50% flows:	1.72	Total of Observed Lowest 50% flows:	1.50
Simulated Summer Flow Volume (months 7-9):	1.84	Observed Summer Flow Volume (7-9):	1.58
Simulated Fall Flow Volume (months 10-12):	2.32	Observed Fall Flow Volume (10-12):	2.08
Simulated Winter Flow Volume (months 1-3):	5.31	Observed Winter Flow Volume (1-3):	5.08
Simulated Spring Flow Volume (months 4-6):	2.99	Observed Spring Flow Volume (4-6):	2.79
Total Simulated Storm Volume:	4.97	Total Observed Storm Volume:	4.10
Simulated Summer Storm Volume (7-9):	0.69	Observed Summer Storm Volume (7-9):	0.63
<i>Errors (Simulated-Observed)</i>	<i>Error Statistics</i>	<i>Recommended Criteria</i>	
Error in total volume:	7.57	10	
Error in 50% lowest flows:	12.80	10	
Error in 10% highest flows:	4.74	15	
Seasonal volume error - Summer:	14.36	30	
Seasonal volume error - Fall:	10.61	30	
Seasonal volume error - Winter:	4.34	30	
Seasonal volume error - Spring:	6.78	30	
Error in storm volumes:	17.54	20	
Error in summer storm volumes:	8.18	50	

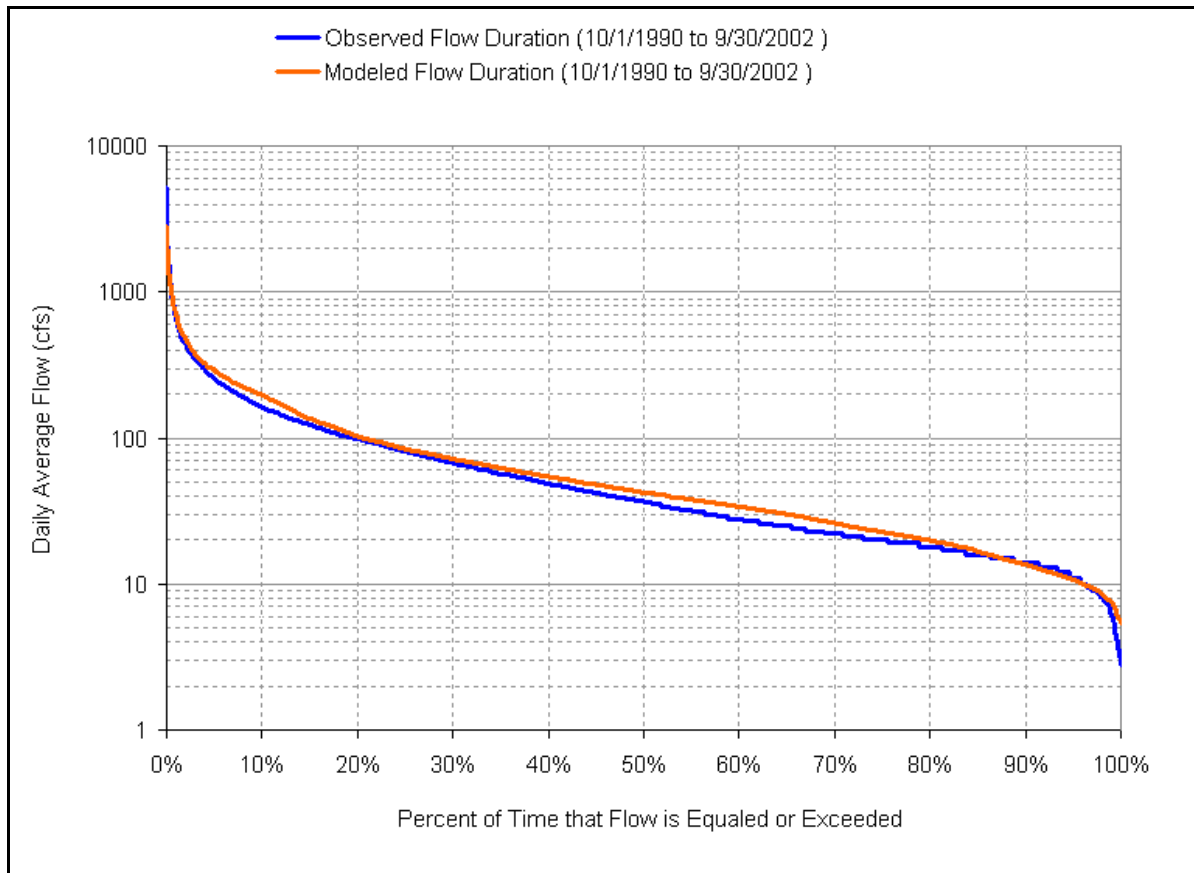


Figure 4.9 Model versus observed flow duration-exceedance curves for 1990 to 2002 at USGS01632900

It is important to note that although the semi-log plot allows for comparative visualization of flows that span several orders of magnitude, this type of graph tends to diminish the differences in high flows, while exaggerating the differences in low flows. The validity of any hydrology calibration must be evaluated using multiple comparisons like those shown previously.

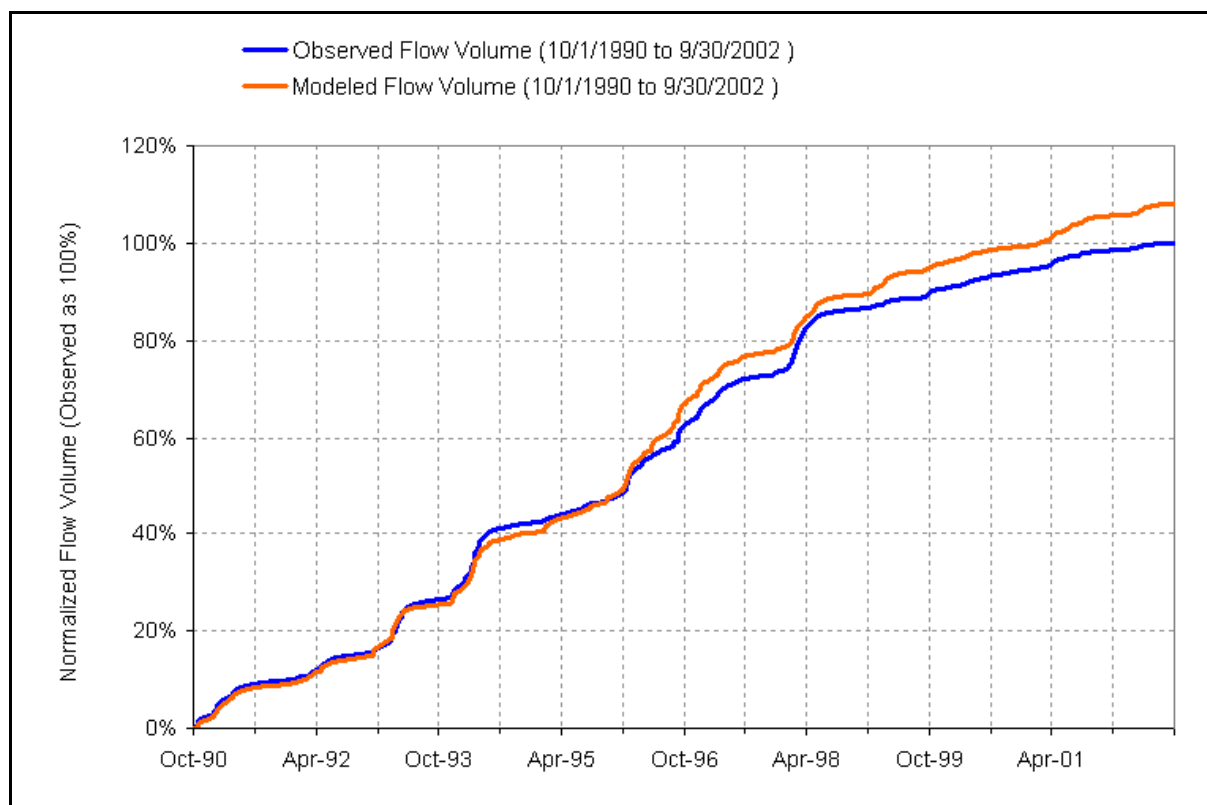


Figure 4.10 Modeled versus observed cumulative flow curves for 1990 to 2002 at USGS01632900

Fecal coliform accumulation and surface loading parameters for land uses were calculated based on contributions from various sources, as discussed in Section 3. After incorporating these model parameters and inputs, as well as contributions from livestock and wildlife point sources, septic systems, and background concentrations in the streams, modeled in-stream fecal coliform bacteria concentrations were compared to observed data. The modeled concentrations closely correspond to the observed fecal coliform values at VADEQ station 1BHKS000.96, as shown in Figures 4.11 and 4.12. Additional comparisons were made between the modeled bacteria concentrations and the data collected at Page County Water Quality Advisory Committee stations and other VADEQ stations in the Hawksbill Creek watershed. The relative pattern of observed concentration levels is maintained in the modeled concentrations. It should be noted that the difference between the highest fecal coliform observed values and the modeled peak concentrations is due to laboratory detection limits which cap the maximum reported concentration at 8,000 cfu/100mL. Because of these maximum laboratory detection limits, the measured value of the sample may be significantly lower than the actual value. Additional comparisons were made between the modeled bacteria concentrations and the data collected at Page County Water Quality Advisory Committee stations and other VADEQ stations in the Hawksbill Creek watershed.

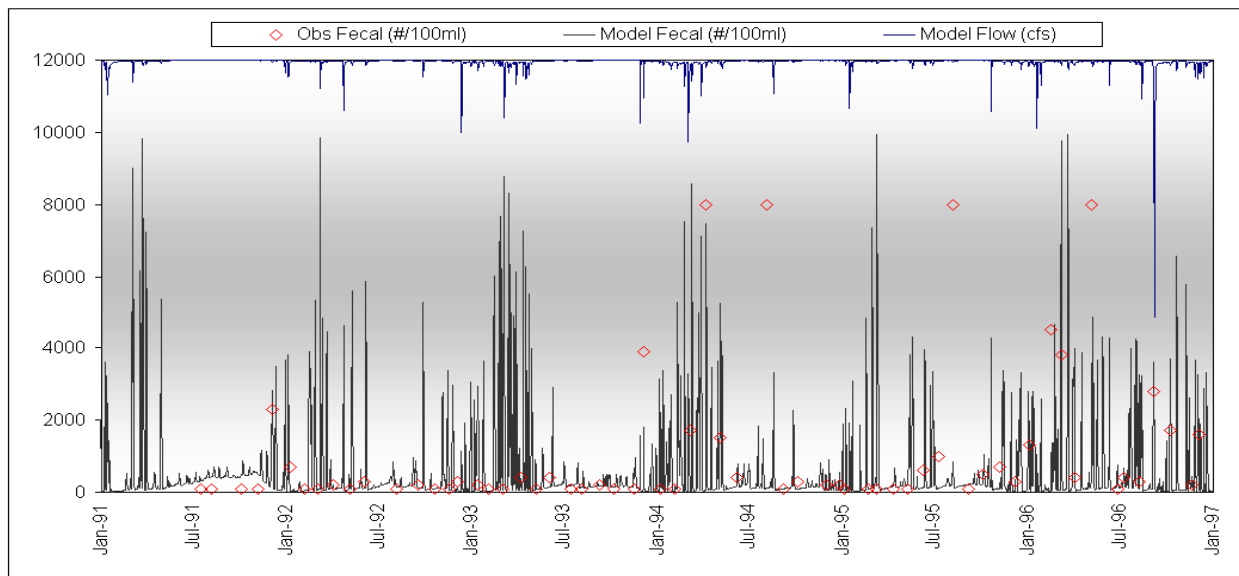


Figure 4.11 Water quality calibration at 1BHKS000.96 on Hawksbill Creek 1991 to 1996

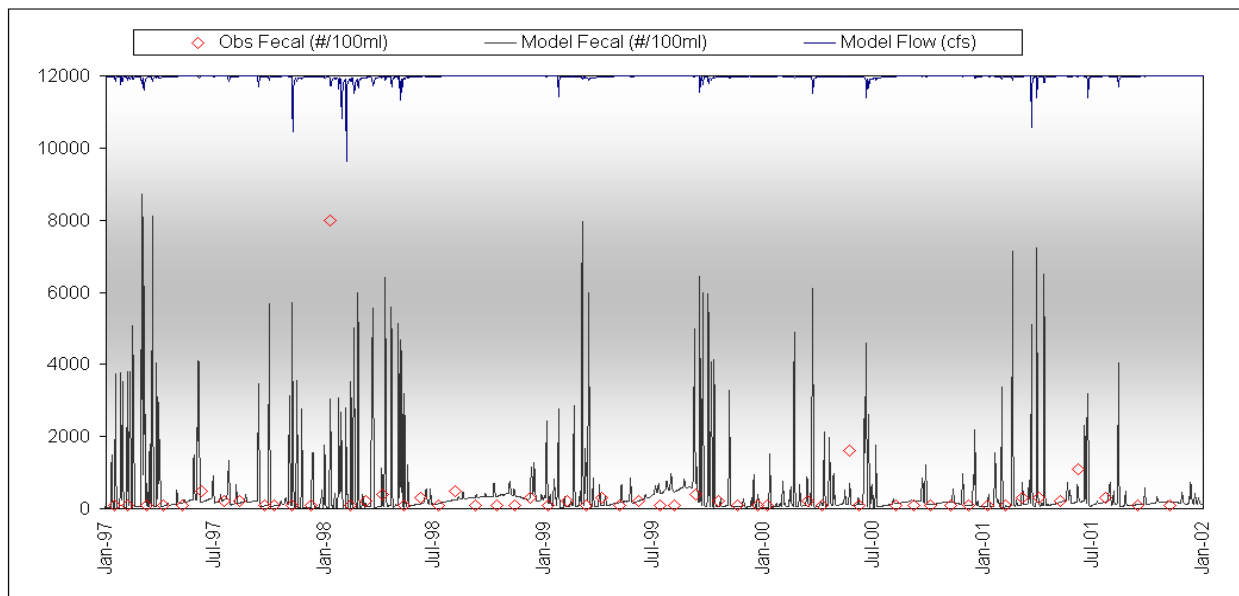


Figure 4.12 Water quality validation at 1BHKS000.96 on Hawksbill Creek 1997 to 2002

4.7 Existing Loadings

The model was run for the representative hydrologic period January 1, 1980 through December 31, 2002. The modeling run represents the existing bacteria concentrations and loadings at the watershed outlet. Figure 4.13 shows the time-series instantaneous and geometric mean

concentrations of estimated *E. coli* for Hawksbill Creek under existing conditions, using the DEQ fecal coliform bacteria/*E. coli* translator. These data were compared to the 126 cfu/100mL geometric mean and 235 cfu/100mL single sample water quality standards for *E. coli* to assess the magnitude of in-stream concentrations. Existing *E. coli* loadings by land use category for Hawksbill Creek are presented in Sections 5. These values represent the contribution of *E. coli* loads from all sources in the watershed.

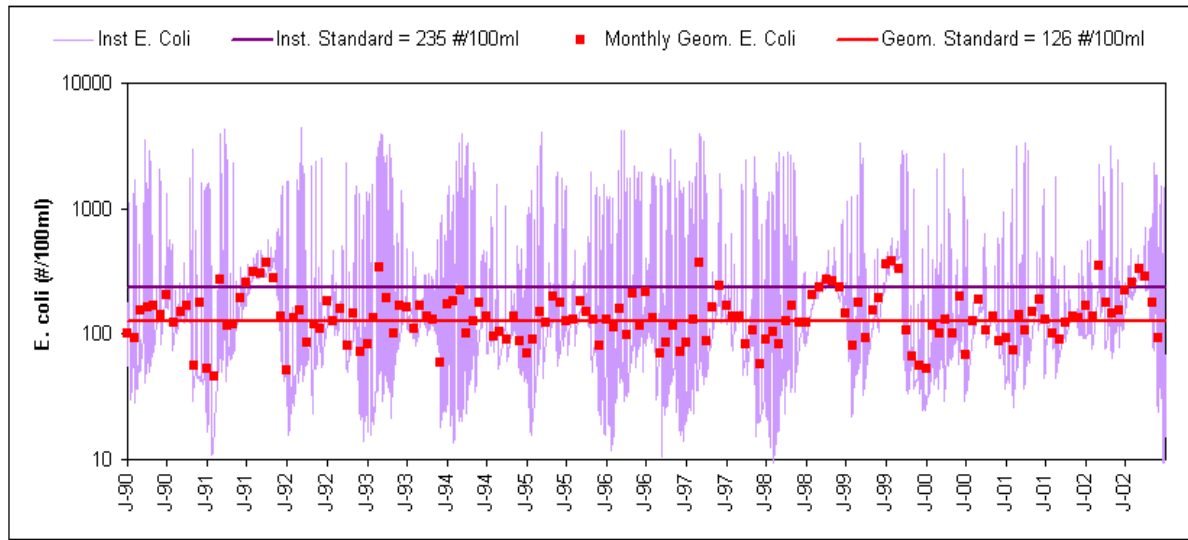


Figure 4.13 Instantaneous and geometric mean concentrations of *E. coli* 1990 to 2002

SECTION 5

TMDL METHODOLOGY

5.1 TMDL Calculation

The *E. coli* bacteria TMDL established for Hawksbill Creek consists of a point source waste load allocation (WLA), a nonpoint source load allocation (LA), and a margin of safety (MOS). The TMDL is the total amount of a pollutant that can be assimilated by the receiving waterbody while still achieving water quality standards. For *E. coli*, TMDLs are expressed in terms of bacteria counts (or resulting concentration).

The TMDL equation is as follows:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS}$$

The WLA portion of this equation is the total loading assigned to point sources (e.g., sewage treatment plants or municipal separate storm sewer system (MS4) permits). The LA portion represents the loading assigned to nonpoint sources (e.g., failing septic discharges, cattle direct deposition). The MOS accounts for any uncertainty in the data and the modeling process. Implicit MOS factors were incorporated into the TMDL development process through the use of conservative model assumptions and source load estimates.

5.2 Wasteload Allocations

There are currently three point source permits in the Hawksbill Creek watershed (Table 5.1). These point sources potentially discharge bacteria to streams in the Hawksbill Creek watershed, as detailed in Section 3.

Table 5.1 VPDES point sources and existing loads

Permit No.	Facility	Flow (MGD)	Permit Limit (E. coli cfu/100ml)	Existing Annual Load (E. coli cfu/yr)
VA0024406	Big Meadows STP	0.13	126	2.26E+11
VA0024422	Skyland Developed Area	0.07	126	1.22E+11
VA0062642	Luray STP	1.60	126	2.79E+12
Total	All Permits	1.80		3.13E+12

5.3 Load Allocations

Load allocations to nonpoint sources are divided into land-based loads from land uses in the watershed and direct discharges from straight pipes, cattle, and wildlife. Failing septic discharges and pet loads were included in the built up (urban) load.

Using the model developed to represent existing conditions, various allocation scenarios were examined for reducing *E. coli* loads to levels that would result in the attainment of water quality standards. This examination focused on understanding the water quality response and sensitivity of Hawksbill Creek to variations in source loading characteristics.

Allocation scenarios are presented with percent violations between 1/1/1990 and 12/31/2002 in Table 5.2. Scenario 8 presents the source reductions required to achieve the *E. Coli* instantaneous and calendar month geometric mean criteria. Scenario 5 presents the reductions required to meet the Stage 1 implementation goal of <10% violation of the instantaneous criteria. The calendar month geometric mean concentration for existing and the final allocation scenario are shown in Figure 5.1. The instantaneous concentration for existing and the final allocation scenario are shown in Figure 5.2. Reductions in load contributions from in-stream sources had the greatest impact on *E. coli* concentrations. Significant reductions from land-based loadings were also required to meet the standard. Direct deposition during low flow conditions and loads transported by runoff during high flow conditions are controlled in these allocation scenarios.

To account for possible future growth in the *E. coli* load contributed by point source facilities in the watershed, the model was run with the load contributed by each point source multiplied by a factor of 5. This change did not result in an increase in the instantaneous criteria (235 cfu/100ml) percent violation rate (0%). The calendar month geometric mean (126 cfu/100ml) violation rate also did not change. See Appendix A for figures showing the instantaneous and geometric mean allocation concentrations for Hawksbill Creek including this point source future growth scenario. The existing load contributed by each facility is presented in the following tables and figures.

Table 5.2 TMDL allocation scenarios and percent violations

Scenario Number	Direct (Instream) Sources			Indirect (NPS) Sources				Percent Violations	
	Straight Pipes	Livestock	Wildlife	Cropland	Pasture	Built up	Forest	Inst. Exceeds 235 cfu/100ml	Geom. Exceeds 126 cfu/100ml
1	0	0	0	0	0	0	0	27%	59%
2	100	25	0	25	25	50	0	19%	33%
3	100	50	0	40	40	50	0	14%	15%
4	100	75	0	50	50	75	0	11%	7%
5	100	80	0	60	60	80	0	10%	3%
6	100	80	0	75	75	80	0	8%	1%
7	100	95	0	90	90	95	0	2%	0%
8	100	97	0	97	97	97	0	0%	0%

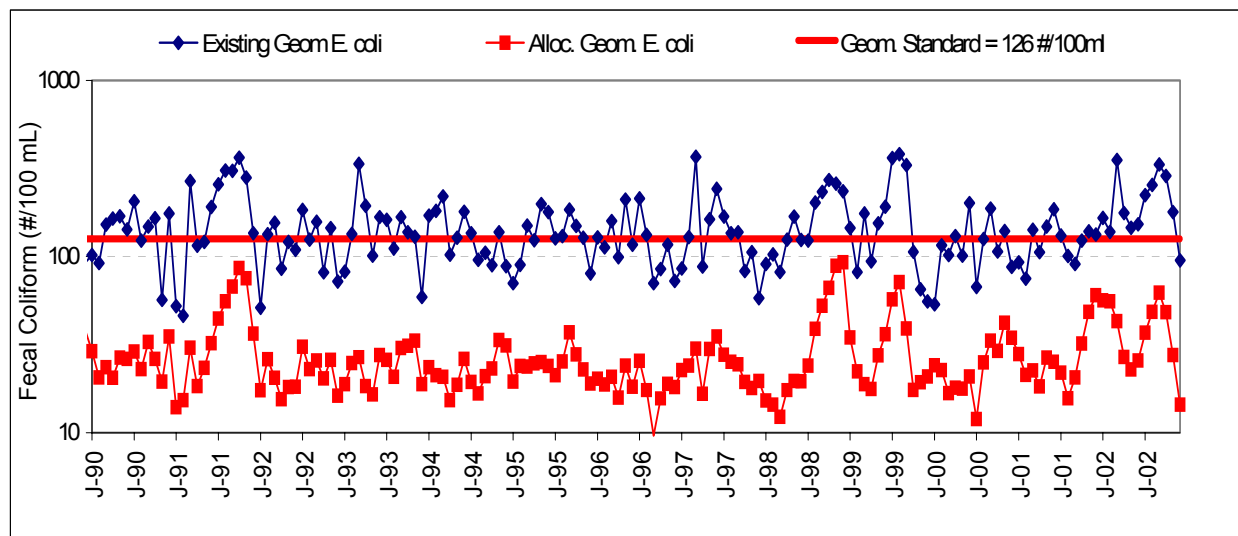


Figure 5.1 Calendar month geometric mean concentrations for existing and final allocation scenario

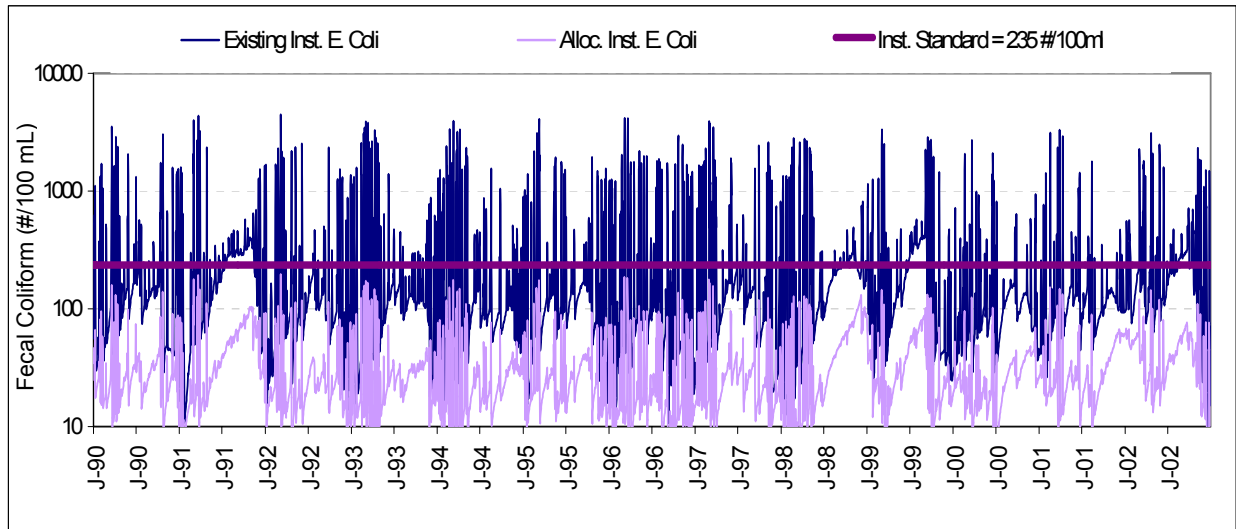


Figure 5.2 Instantaneous concentrations for existing and final allocation scenario

The Load Allocations (LAs) and Waste Load Allocations (WLAs) under Scenario 8 are presented in Table 5.3 and Table 5.4, respectively. The load allocation in this scenario includes a 97% reduction in cropland, pasture, and built-up land-based sources in the watershed. No reductions are required in forest land-based sources in the watershed. In addition, this load allocation scenario includes a 100% reduction in direct deposition of *E. coli* bacteria from straight pipes, and a 97% reduction in direct deposition of *E. coli* bacteria from livestock. No reduction in direct deposition of *E. coli* bacteria from wildlife is required. The TMDL is presented in Table 5.5.

Table 5.3 Existing and allocation loads for LAs under allocation scenario 8

Sources		Total Annual Loading for Existing Conditions (cfu/yr)	Total Annual Loading for Allocation Conditions (cfu/yr)	Percent Reduction
Direct	Straight Pipes	<1.00E+4	<1.00E+4	100%
	Livestock	2.28E+13	6.85E+11	97%
	Wildlife	6.76E+12	6.76E+12	0%
Indirect	Cropland*	4.13E+13	1.24E+12	97%
	Pasture**	9.32E+13	2.80E+12	97%
	Built up***	9.32E+13	2.80E+12	97%
	Forest****	1.26E+12	1.26E+12	0%
Total		2.59E+14	1.55E+13	94%

* Includes Stipmining and Barren

** Includes Hayland

*** Includes Non MS4 Urban Pervious and Urban Impervious

**** Includes Wetland

Table 5.4 Existing and allocation loads for WLAs under allocation scenario 8

Sources	Total Annual Loading for Existing Conditions (cfu/yr)	Total Annual Loading for Allocation Conditions (cfu/yr)	Percent Reduction
Permits*	3.13E+12	3.13E+12	0%

* Total for all permits

Table 5.5 *E. coli* TMDL for Hawksbill Creek

WLA	LA	MOS	TMDL
3.13E+12	1.55E+13	Implicit	1.87E+13

5.4 Consideration of Critical Conditions

The LSPC model is a continuous-simulation model; therefore, all flow conditions are taken into account for loading calculations. The modeling period represents typical high and low flow periods in the watershed; therefore, loads contributed through direct deposition (e.g., cattle in streams) and through runoff under critical conditions were accounted for in the model.

5.5 Consideration of Seasonal Variations

Seasonal variation was explicitly included in the modeling approach for this TMDL. Bacteria accumulation rates for each land use were determined on a monthly basis. The monthly accumulation rates accounted for the temporal variation in activities within the watershed, including seasonal application of agricultural waste, grazing schedules of livestock, and seasonal variation in number of cows in the stream. Also, the use of continuous simulation modeling resulted in consideration of the seasonal aspects of rainfall patterns. In addition, seasonal variation was accounted for in the allocation scenario.

SECTION 6

REASONABLE ASSURANCE AND IMPLEMENTATION

6.1 TMDL Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments on Hawksbill Creek. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan, and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at <http://www.deq.state.va.us/tmdl/implans/ipguide.pdf>. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

6.2 Staged Implementation

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, for the bacteria TMDL the following stage 1 scenarios are targeted at controllable, anthropogenic bacteria sources and can serve as starting points for targeting BMP implementation activities.

6.3 Stage 1 Scenario

The goal of the stage 1 scenario is to reduce the bacteria loadings from controllable sources, such that violations of the single sample maximum criterion (235 cfu/100mL) are less than 10 percent. The stage 1 scenario was generated with the same model setup as was used for the TMDL allocation scenarios. This scenario is presented with the other allocation scenarios in Section 5.

6.4 Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay. Several BMPs known to be effective in controlling bacteria have also been identified for implementation as part of the 2001 Interim Nutrient Cap Strategy for the Shenandoah/Potomac basin. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of the strategy described under nonpoint source implementation mechanisms. (2001 Draft Interim Nutrient Cap Strategy for the Shenandoah/Potomac River Basins). The BMPs required

for the implementation of the sediment allocations in the watersheds contribute directly to the sediment reduction goals set as part of the Chesapeake Bay restoration effort. A new tributary strategy is currently being developed for the Shenandoah-Potomac River Basin to address the nutrient and sediment reductions required to restore the health of the Chesapeake Bay. Up-to-date information on tributary strategy development can be found at <http://www.snr.state.va.us/Initiatives/TributaryStrategies/shenandoah.cfm>.

6.5 Reasonable Assurance for Implementation

6.5.1 Follow-Up Monitoring

VADEQ will continue monitoring bacteria levels at current, long-term stations in the Hawksbill Creek watershed, in accordance with its ambient monitoring program to evaluate reductions in fecal bacteria counts and the effectiveness of TMDL implementation in attainment of water quality standards.

6.5.2 Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plans, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plans into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and

TMDL implementation plans developed within a river basin.

6.5.3 Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

SECTION 7

PUBLIC PARTICIPATION

A stakeholder and TMDL study kickoff meeting was held on July 23, 2003 at the Page County Courthouse in Luray, Virginia. A site visit to the Hawksbill Creek watershed was also conducted on this date. Important information regarding likely stressors and sources was discussed with state environmental personnel and local stakeholders. A meeting was held with local farmers with the Page County Farmers Association on October 9, 2003 to discuss livestock data and farming practices.

The first public meeting on the development of a TMDL for the Hawksbill Creek watershed was held on August 26, 2003 from 7-10 p.m. at the Page County Courthouse in Luray, Virginia. Approximately 49 people attended. Copies of the presentation materials were made available for public distribution at the meeting. No written comments were received.

The second public meeting on the TMDL development for the Hawksbill Creek watershed will be held on March 18, 2004 from 7-10 p.m. at the Page County Courthouse in Luray, Virginia. Approximately 42 people attended. Copies of the Draft TMDL report and presentation materials were made available for public distribution at the meeting. Written comments were received and responded to by VADEQ.

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Glossary

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)

Ambient water quality. Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.

Background levels. Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.

Bacteria. Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.

Bacterial decomposition. Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

Basin. A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.

Best management practices (BMPs). Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Calibration. The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Clean Water Act (CWA). The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.

Concentration. Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).

Confluence. The point at which a river and its tributary flow together.

Contamination. The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.

Conventional pollutants. As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.

Cost-share program. A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).

Critical condition. The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.

Decay. The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.

Decomposition. Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also Respiration.

Designated uses. Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.

Discharge. Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.

Discharge Monitoring Report (DMR). Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.

Discharge permit (see VPDES). A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System (NPDES), under provisions of the Federal Clean Water Act.

Domestic wastewater. Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.

Dynamic model. A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.

Effluent. Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.

Endpoint. An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Existing use. Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).

E. coli. *Escherichia coli* is a bacterium that is commonly found in the digestive tract of warm blooded animals. Various strains can cause gastrointestinal illness and other infections.

Enterococci. A subgroup of fecal streptococci bacteria that can cause gastroenteritis.

Failing Septic System. Typically an older or improperly maintained septic systems that discharges waste to the soil surface where it is available for washoff into surface waters.

Fecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth.

Ground water. The supply of fresh water found beneath the earth's surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrologic cycle. The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.

Hydrology. The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Indicator organism. An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.

KLSCP. A composite factor used to measure soil loss/erosion (K), the length/slope factor (LS), the vegetation cover factor (C), and the conservation practices factor (P).

Loading, Load, Loading rate. The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.

Load allocation (LA). The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).

Loading capacity. The greatest amount of loading a water can receive without violating water quality standards.

LSPC. Loading Simulation Program C++

Margin of safety (MOS). A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a $TMDL = LC = WLA + LA + MOS$).

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Mitigation. Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace damaged ecosystems.

Monitoring. Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.

MRLC. Multi Resolution Land Characteristics. Land use coverage developed by USEPA and USGS.

MUID. Soil map unit in the STATSGO database developed by NRCS. A map unit is composed of several soil series that have similar properties.

National Pollutant Discharge Elimination System (NPDES). The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.

Natural waters. Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.

NCDC. National Climatic Data Center

NHD. National Hydrography Dataset (developed by USGS)

Nonpoint source. Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

NRCS. Natural Resource Conservation Service.

Numeric targets. A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.

Organic matter. The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.

Permit. An authorization, license, or equivalent control document issued by EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.

Phased Implementation. Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.

Point source. Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste

treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollutant. Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).

Pollution. Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Public comment period. The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a Federal Register notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).

Receiving waters. Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.

Reference watershed. A non-impaired watershed with similar characteristics that is used to define the baseline, reference, or natural condition.

Residence time. Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.

Restoration. Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.

Riparian areas. Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.

Riparian zone. The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.

Runoff. That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Septic system. An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Sewer. A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.

Simulation. The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Slope. The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

STATSGO. State Soil Geographic database developed by NRCS

Straight Pipe. Illicit and untreated discharge of waste typically from a private home.

Surface water. All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (e.g. 15-minutes, 1-hour, 1-day).

Topography. The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.

Total Maximum Daily Load (TMDL). The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Tributary. A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.

USEPA. United States Environmental Protection Agency

USGS. United States Geological Survey

USLE. Universal Soil Loss Equation. Equations used to calculate soil loss/erosion.

Validation. Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

VDGIF. Virginia Department of Game and Inland Fisheries.

Virginia Pollutant Discharge Elimination System (VPDES). The Virginia state program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.

Wasteload allocation (WLA). The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).

Wastewater. Usually refers to effluent from a sewage treatment plant. See also Domestic wastewater.

Wastewater treatment. Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or

neutralize contaminants.

Water quality. The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.

Water quality criteria. Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

Water quality standard. Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.

Watershed. A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

WQIA. Water Quality Improvement Act.

APPENDIX A

Point Source - Future Growth Scenario

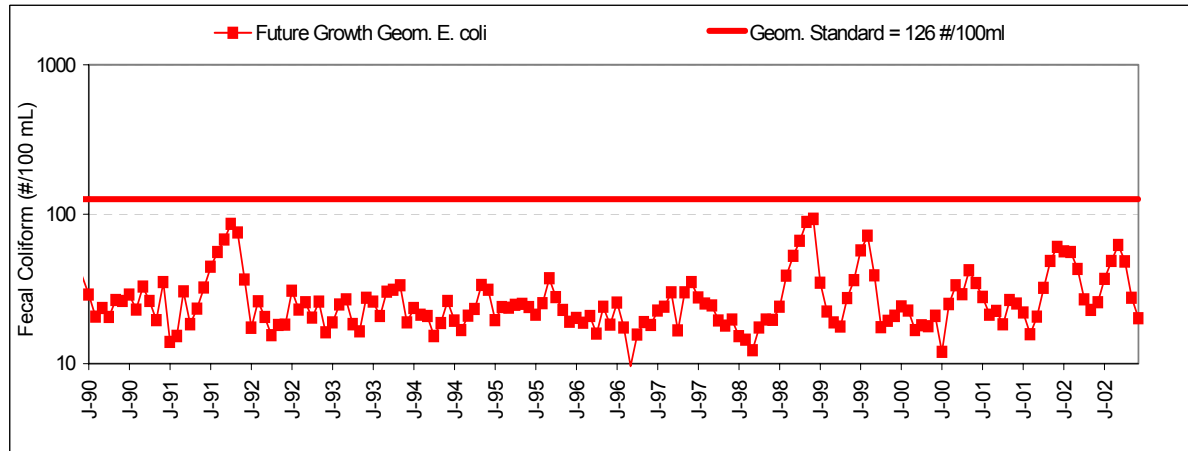


Figure A.1 Calendar month geometric mean concentrations for final allocation scenario, including point source future growth

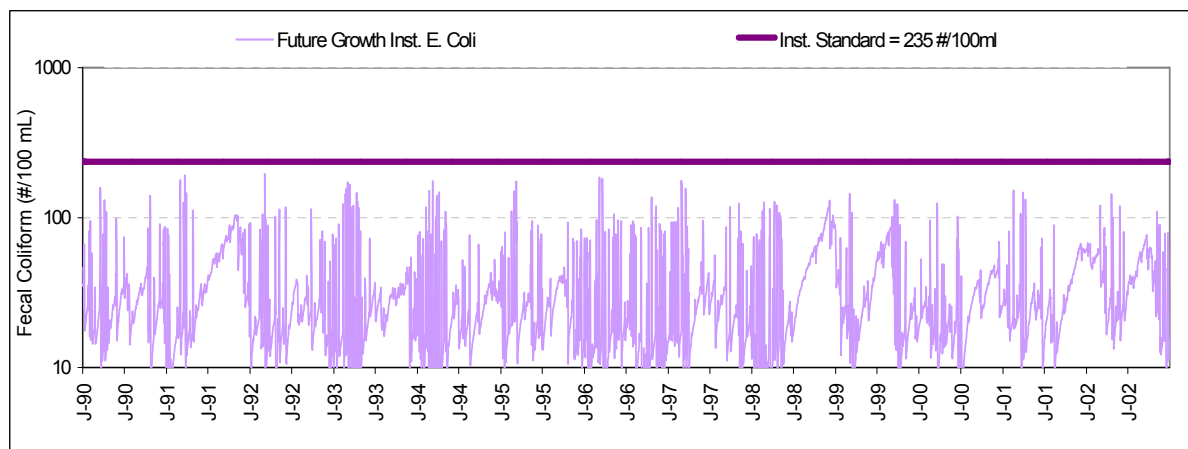


Figure A.2 Instantaneous concentrations for final allocation scenario, including point source future growth